KIB
Seismic Vulnerability Assessment

Prepared for:

Kodiak Island Borough

by:

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1.0 Introduction

This report describes a Seismic Vulnerability Assessment for all of the Kodiak Island Borough school buildings.

1.1 Executive Summary

A Seismic Vulnerability Assessment was performed of the Kodiak Island Borough school buildings. The assessment included all the buildings for 13 schools as well as the Learning Center. Several of the schools include multiple buildings, and each building was included in the assessment.

For each site / building, we evaluated six seismic hazards: ground shaking, surface faulting, liquefaction, tsunami, landslide and differential settlement. Given these seismic hazards, we evaluated how each building might perform in various size earthquakes.

The geologic hazard studies show that the level of earthquake motion that should be used for design of new facilities, to modern (2006) standards, should be about 18% to 40% larger than what was used for the design of most of the schools built since the mid-1960s. The 18% increase would reflect design using the seismic concepts in the Uniform Building Code (1997), which are set at providing for life safety for earthquakes that occur once every 475 years. The 40% increase would reflect design for even rarer earthquakes, as would be required if KIB adopts the latest provisions of the International Building Code, which are set at designing for life safety for 2/3 of an earthquake that might occur once every 2,475 years.

For those buildings where we recommend structural seismic upgrades, the upgrades should be designed to meet the intent of providing life safety service for earthquakes that occur once every 475 years.

For construction of future new buildings, we recommend that the higher standard (2/3 of 2,475 year earthquake) be used. This should provide immediate occupancy for the buildings should a 475-year earthquake occur, while still providing life safety reliability in larger but rarer events.

For most of the buildings, the existing structural systems were designed with a reasonable capability to resist medium to quite large earthquakes. However, for portions of the three oldest buildings (Middle School, Ouzinkie, Peterson), we found there were significant deficiencies in the existing lateral force resisting system, such that a structural upgrade appears warranted. We also found some deficiencies at the High School Library Wing and Gym, largely through strength and stiffness discontinuities that were apparently overlooked in the original design.

In addition, we found that at essentially every school there are a number of non-structural components that require anchorage or bracing. These components range from furnaces, heating and ventilation equipment, water tanks, library bookshelves, suspended ceilings, windows, etc. The cost to upgrade the essential items needed for building services is $348,480 (all schools except Middle School), plus $10,966 for Middle School. The cost to upgrade suspended ceilings just over main egress areas would be an additional

$302,000. The cost to upgrade all suspended ceilings would be $1,189,000. The cost of upgrading suspended ceilings has not been included in Table 1-1.

The complete seismic upgrade program would cost $3,132,290. Table 1-1 summarizes the costs and benefits and the Benefit Cost Ratios (BCR) for the recommended upgrades.

School Building	Seismic Upgrade Cost[1]	Project Benefits	Benefit Cost Ratio
Middle School	$1,251,510[2]	$8,132,160	6.50
Ouzinkie (1969 portion)	$149,000	$975,410	7.55
Peterson (1946 portion)	$508,500	$1,862,173	3.66
High School Library Wing	$464,500	$4,452,695	9.59
High School Gym (Alternative 1[3])	$410,300	$416,768	1.02
Non Structural Items	$348,480		
Total	$3,132,290[4]	$15,839,206	5.06[5]

Table 1-1. Summary of Recommended Seismic Upgrades and BCRs

We performed a series of benefit cost analyses, to examine how cost effective it is to perform the above upgrades. Using a discount rate of 7% and applying the FEMA-approved methodologies to perform such analyses we found that the BCR varies from 1.02 to 9.59 for the recommended six projects when ranked individually, or 5.06 when considered as one large project. Any project with a Benefit Cost Ratio of 1 or larger is deemed cost effective on an economic basis; in other words, the capital cost spent today is less than the benefits accrued from reduction in building damage, injury to people and other economic impacts from all future earthquakes over the remaining lifetime of the schools.

It is our opinion that all of the above listed projects are eligible for co-funding under FEMA's Pre-Disaster Mitigation program. We therefore recommend that KIB consider submitting a proposal to FEMA under its PDM-C 2006 program. The availability of funds under FEMA's 2006 program are uncertain, and it is possible that FEMA will not have sufficient funds in 2006 for all eligible projects.

Should co-funding from FEMA not be available under the FEMA 2006 PDM-C program, we recommend that KIB still implement all of the above projects as soon as funds are available. The work should be prioritized to do early implementation of the projects with the highest BCRs, consistent with permitting, and coordinated with complementary operations and maintenance projects. All work should be completed by 2016 (ten years), reflecting the ongoing risk to the community. If resources are available, it is possible that all upgrades could be completed in four years (by end of summer 2010).

[1] Includes relocation costs during construction.
[2] Includes $10,966 for upgrade of essential non-structural items.
[3] Alternative 1 denotes an upgrade of the Gym to provide improved performance after a design basis earthquake (PGA = 0.47g). See Section 4.5 for a further description.
[4] Budget would be based on rounded figures to the nearest $1,000.
[5] Benefits from upgrade of the non-structural items would modestly increase this value.

1.2 Other Improvements

During the course of our field visits, a few other maintenance related improvements were noted. These include:

- Install new roof at Old Harbor Gym building (improve roof drainage)
- Install new roof at Larsen Bay Gym Building (improve roof drainage)
- Remove soil backfills on walls at Karluk and Akhiok (reduce wall loading, long term water damage to building)

These upgrades would not likely be eligible for FEMA co-funding.

1.3 Report Outline

The outline of the report is as follows:

- Section 2 describes the structural systems for each building where structural retrofits are recommended.
- Section 3 presents the seismic hazards for each building.
- Section 4 describes the Seismic Vulnerability Assessment for each building and describes recommended seismic retrofits for those buildings where upgrades are warranted and cost effective.
- Section 5 describes the fragility and damage states for each building selected for seismic upgrade. Section 5 also presents risk summaries for all buildings, even those not recommended for seismic upgrade.
- Section 6 describes the benefit cost analyses in context of FEMA's PDM-C program.

1.4 Abbreviations and Definitions

BCR	Benefit Cost Ratio
CMU	Concrete masonry unit
FEMA	Federal Emergency Management Agency
KIB	Kodiak Island Borough
KMS	Kodiak Middle School
g	acceleration (1g = 32 feet / second / second)
M	Magnitude (moment)
PDM-C	Pre Disaster Mitigation - Competitive
PGA	Peak Ground Acceleration (units in g)
psf	pounds per square foot
UBC	Uniform Building Code
V	Code based term for seismic base shear forces
W	Code based term for weight of the building used in seismic evaluations

In this report, we generally use the term "Kodiak" or "Kodiak Island" to refer to the entire island, and "Kodiak City" to refer just to the geographic area of the city.

1.5 Limitations

The findings in this report are meant as a structural / earthquake condition assessment of each building for purposes of developing a cost effective seismic retrofit program for the Kodiak Island Borough. These evaluations are also used to perform benefit cost analyses as part of the FEMA PDM-C.

1.6 Acrobat File Format

If you are viewing a .pdf version of this report, you should use Acrobat Reader version 7 (free from www.adobe.com) or the full version of Acrobat 7. Prior versions of Acrobat may scramble some fonts.

1.7 Acknowledgements

This report was written by John Eidinger and Donald Duggan of G&E Engineering Systems Inc. Benefit cost analyses were developed by Ken Goettel of Goettel & Associates, Inc. Geologic and geotechnical hazards were developed by William Lettis, Rob Witter, Jeff Bacchuber, Scott Lindvall and Rick Ortiz of William Lettis and Associates, Inc.

Many KIB staff and Kodiak residents participated in this effort, providing project coordination, access to schools, attendance and review of presentations and draft reports, including: Bud Cassidy, Ken Smith, Sharon Lea Adinolfi, Robert Tucker, Gregg Hacker, Gary Carver (Carver Geologic Inc.), Rick Gifford, Duane Dvorak, Scott Arnot, Brent Watkins and Larry Ledoux.

2.0 Building Descriptions

Section 2 describes the structural systems at each school building that were found to have potential need for seismic upgrade to the structural system.

Several of KIB's facilities have had successive renovations / remodels over the past 50 years or so. Different types of structural systems are used within one "building complex". This is the case for the High School, Middle School, Peterson School, Larsen Bay School and Ouzinkie School. We have considered the different seismic capacity of each portion of these buildings.

2.1 Facility Inventory

KIB owns and maintains 14 school facilities in Kodiak, Alaska, Figure 2-1.

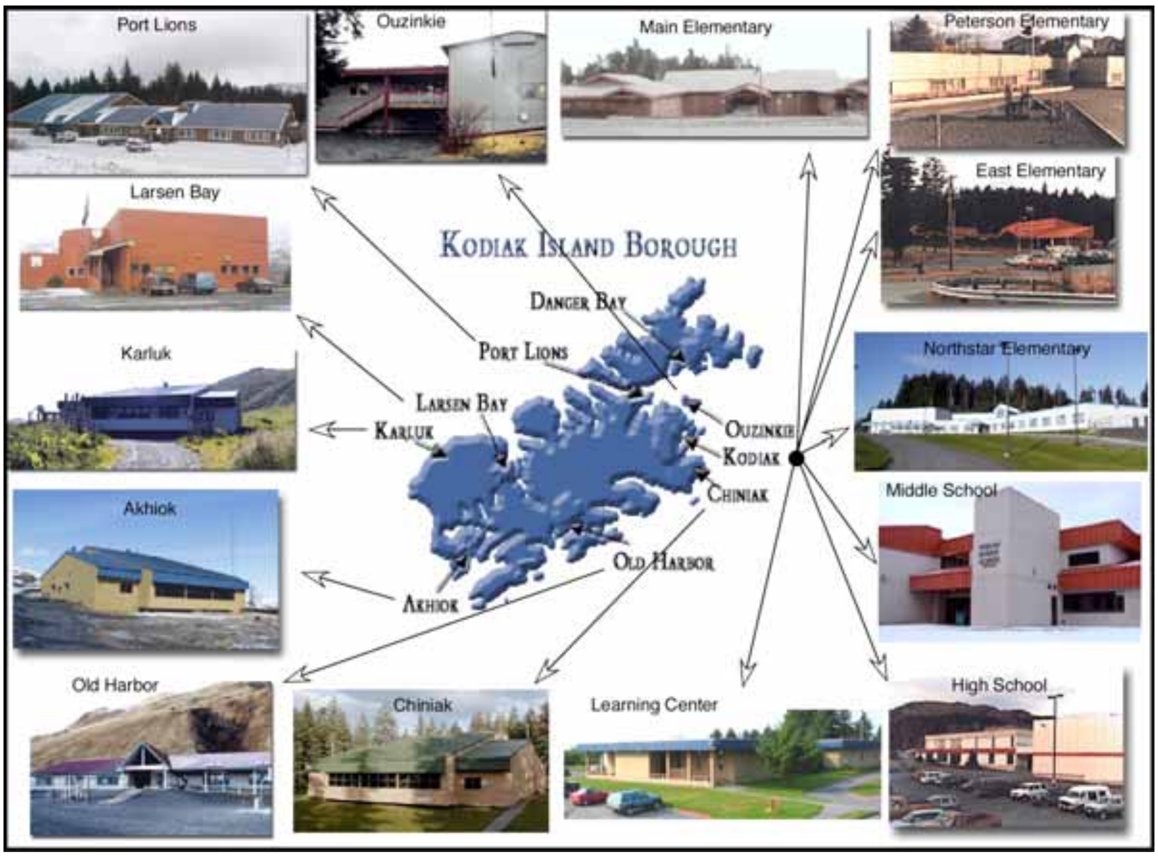

Figure 2-1. KIB School Facilities

Table 2-1 lists the schools and buildings along with square footage and historical replacement values.

Building	Square Footage (Approx.)	Year Designed / Built	Historical Replacement Value ($)	Replacement Value ($/sq. ft,)
Learning Center	8,323	1968	$514,315	$61.79
High School Vocational West and East Wings	60,069	1966	$11,005,341	$183.21
High School Gym (basketball)	20,000	1972	$3,664,233	$183.21
High School Library Wing (2 story)	27,280	1972	$4,998,014	$183.21
High School Pool	18,675	1972	$3,421,478	$183.21
High School Kitchen Addition	1,560	1993	$285,810	$183.21
High School Mat Room	8,448	1995	$1,547,772	$183.21
Maintenance Shop	16,993	1985		
Auditorium	48,004	1984	$8,794,892	$183.21
Middle School Southwest Corner	15,000	1952	$2,100,000	$140.00
Middle School Gym and adjacent classrooms	15,000	1954	$2,100,000	$140.00
Middle School north classroom addition	5,000	1959	$691,000	$138.20
Middle School extreme north classroom addition	5,000	1962	$691,000	$138.20
Middle School East additions	20,000	1962, 1983	$2,764,000	$138.20
Main Elementary	37,830	1983	$9,260,325	$244.79
Northstar Elementary	39,600	1995	$4,022,880	$101.59
Peterson Elementary	39,967	1946, 1956, 1993, 1998	$5,921,468	$148.16
Chiniak	7,682	1984	$1,440,000	$187.45
Old Harbor Old Gym	6,855	1980	$1,293,790	$188.74
Old Harbor Classroom Bldg	10,472	1989	$1,976,450	$188.74
Akhiok	7,769	1982	$1,620,000	$208.52
Karluk	7,522	1983	$1,620,000	$215.37
Larsen Bay Gym	10,772	1980, 1988	$3,351,960	$167.45
Larsen Bay Classroom Bldg	9,246	1988	$1,891,593	$175.60
Port Lions	20,836	1989	$1,767,267	$175.60
Ouzinkie	11,701	1980, 1985, 1994	$1,512,000	$129.22
Total			$89,568,644	

Table 2-1. Buildings and Replacement Values (Historical)

In Table 2-1, the replacement values are based on information provided by KIB, much of which is dated (historical). In cases where a building has multiple sections (like Old Harbor), the KIB replacement value data was calculated per square foot, and then the same dollar per square foot was applied to get the value of each portion of the building. Overall, the values listed in Table 2-1 are considerably low. For purposes of seismic evaluations, should a building be seriously damaged in an earthquake, it will likely have to be re-built by first demolishing and off-hauling the existing structure, changing the foundations, and then constructing a new building. Construction costs for 2006 are, on average, about $250 per square foot for buildings in Kodiak that have limited quantities of plumbing fixtures, HVAC equipment, suspended ceilings, etc.; and $350 per square foot for buildings with more such components and equipment, which is more typical for many KIB schools.

Given that the building replacement values in Table 2-1 are "historical", it was decided to update the building replacement values using the modern Alaska school building cost estimating model. This was done for four buildings that are candidates for seismic upgrade:

Building	Square Footage (Approx.)	Year Basis	Replacement Value ($)	Replacement Value ($/sq. ft,)
High School Library	21,943	2006	$6,861,376	$312.69
Middle School Original Construction	26,009	2006	$7,626,227	$293.21
Peterson, 1946 Construction	17,000	2006	$4,396,530	$325.86
Ouzinkie, 1969 Construction	4,452	2006	$1,719,336	$386.19

Table 2-2. Building Replacement Values ($2006)

These Building Replacement Values vary between $293 to $386 per square foot, using year 2006 dollars. These replacement costs are used as one of the factors in preparing the benefit cost analyses, with the replacement value per square foot entered directly into the FEMA benefit cost analysis software[6]. In the following analyses for replacement costs, the soft costs (engineering, inspection, construction inspection) vary between the projects, reflecting the complexity of the design (replacement of a portion of a building is more complex than building a brand new building without interfaces to the adjacent buildings), and location of the work (additional cost needed for work in village schools due to transportation and access issues).

Middle School Original Construction

A cost estimate was developed for the replacement of the old wing of the Middle School. The replacement costs are based on State of Alaska standardized cost estimates, adjusted for Kodiak City. The cost estimate was prepared September 20, 2005.

For construction of a new 26,009 square foot building, the construction cost is $6,004,903, and soft costs[7] is $1,621,324, or a total of $7,626,227 ($293.21 per square foot). This cost allows for:

- 8,995 square feet of standard classrooms (teaching area)
- 514 square feet of music classroom (teaching area)
- 2,365 square feet of library and media center (teaching area)
- 1,289 square feet of home economics
- 5,404 square feet of industrial arts
- 497 square feet of lockers / showers
- 325 square feet storage
- 1,329 square feet toilets

[6] Note. For some of the retrofits, the actual square footage of the retrofit area is a little different than the square footage used in these building replacement value analyses. There is no impact to the analyses as the unit value per square foot is used for the actual retrofit project.

[7] Soft costs include construction management, owner's project management, design costs, indirect / administration, equipment costs, art and contingency.

- 4,719 square feet circulation
- 1,673 square feet mechanical / electrical

These costs include 11.4% escalation for Kodiak City location (no escalation for Anchorage), and are based on 2006 costs. Soft costs include 5% construction management by consultant, 3% construction management by owner, 10% design fee, 3% KIB administrative and indirect costs, 5% for equipment costs, 1%[8] for art costs.

High School Library

A cost estimate was developed for the replacement of the High School Library Wing. The replacement costs are based on State of Alaska standardized cost estimates, adjusted for Kodiak City. The cost estimate was prepared September 20, 2005.

For construction of a new 21,943 square foot building[9], the construction cost is $5,402,658, and soft costs is $1,458,718, or a total of $6,861,376 ($312.69 per square foot). This cost allows for:

- 4,718 square feet of standard classrooms (teaching area)
- 2,832 square feet of laboratory classroom (teaching area)
- 3,447 square feet of library and media center (teaching area)
- 5,168 square feet multipurpose room
- 356 square feet administration
- 1,233 square feet cafeteria / food preparation
- 267 square feet storage
- 64 square feet toilets
- 3,792 square feet circulation
- 66 square feet mechanical / electrical

These costs include 11.4% escalation for Kodiak City location (no escalation for Anchorage), and are based on 2006 costs. Soft costs include 5% construction management by consultant, 3% construction management by owner, 10% design fee, 3% KIB administrative and indirect costs, 5% for equipment costs, 1% for art costs.

Peterson 1946 and 1956 Construction

A cost estimate was developed for the replacement of oldest portions of the Peterson school, designed/built in 1946 and 1956. The replacement costs are based on State of Alaska standardized cost estimates, adjusted for Kodiak City. The cost estimate was prepared October 11, 2005.

For construction of a new 17,000 square foot building, the construction cost is $4,396,530, and soft costs is $1,143,097, or a total of $5,539,627 ($325.86 per square foot). This cost allows for:

- 8,122 square feet of standard classrooms (teaching area)
- 1,012 square feet of kindergarten /primary classroom (teaching area)
- 906 square feet of administration offices

[8] Art costs are a statutory required cost element for construction of schools in Kodiak.
[9] This area excludes the commons areas that are included in Table 2-1.

- 2,130 square feet of cafeteria / food preparation area
- 2,365 square feet of library and media center (teaching area)
- 348 square feet storage
- 1,084 square feet toilets
- 2,898 square feet circulation
- 500 square feet mechanical / electrical
- crawl space under the first floor
- demolition of the existing building

These costs include 11.4% escalation for Kodiak City location (no escalation for Anchorage), and are based on 2006 costs. Soft costs include 5% construction management by consultant, 3% construction management by owner, 12% design fee, 5% KIB administrative and indirect costs, 1% for art costs.

Ouzinkie 1969 Construction

A cost estimate as developed for the replacement of the old central portion of Ouzinkie School. The replacement costs are based on State of Alaska standardized cost estimates, adjusted for Kodiak City. The cost estimate was prepared October 11, 2005.

For construction of a new 4,452 square foot building, the construction cost is $1,322,566, and soft costs is $396,769, or a total of $1,719,336 ($386.19 per square foot). This cost allows for:

- 2,362 square feet of standard classrooms (teaching area)
- 434 square feet of library and media center (teaching area)
- 75 square feet of administration area
- 638 square feet storage
- 349 square feet toilets
- 540 square feet circulation
- 54 square feet mechanical / electrical
- crawl space under the first floor
- demolition of the existing building

These costs include 22.4% escalation for Ouzinkie location (requires boat / air service from Kodiak City), and are based on 2006 costs. Soft costs include 6% construction management by consultant, 4% construction management by owner, 14% design fee, 5% KIB administrative and indirect costs, 1% for art costs.

2.2 Middle School

The Kodiak Middle School (KMS) was built in several stages. The original portion (now the southwest corner) of the building was built in 1952. Substantial additions were made in 1954, 1959[10] and 1962. A minor addition and a renovation was made in 1983. Figures 2-1, 2-2 and 2-3 outline the various additions and floor plans of the building.

As will be further described in Section 4, the 1952 original and 1954 additions have poor seismic capacity. We reviewed the various additions that were made (1962, 1983

[10] Original drawings suggest that the northwest "1962" Addition shown in Figure 2-1 was designed in 1959, but built in 1962.

renovation) and found that none of the additions or renovations made material improvements to the structural (lateral force resisting system) systems of the prior-constructed buildings.

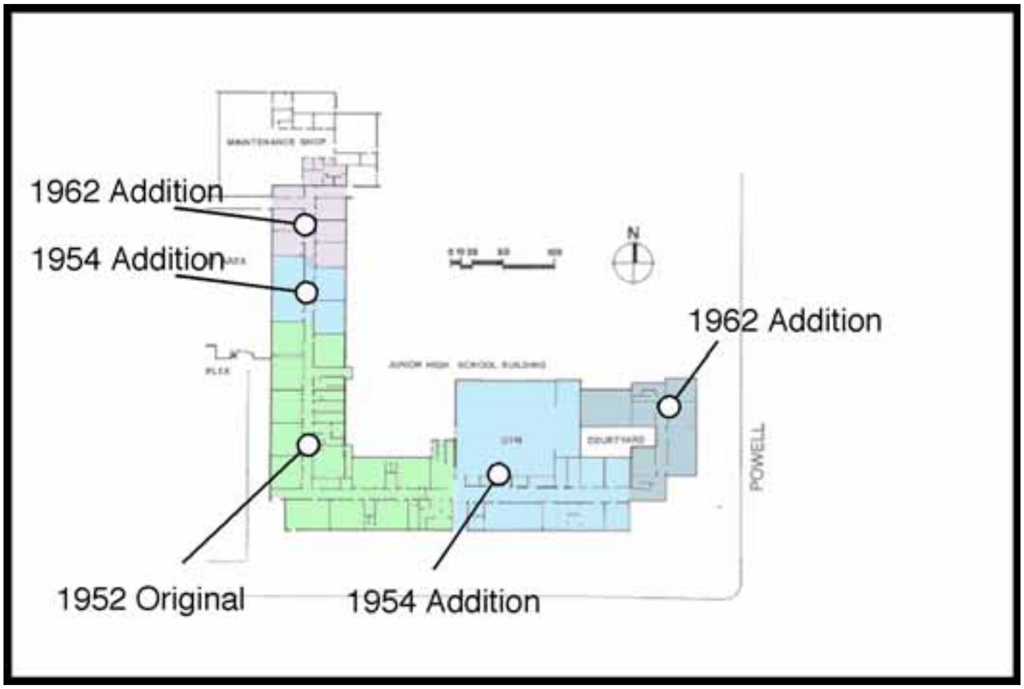

Figure 2-1. Middle School

The building as it is built today consists of various types of structural systems. The original 1952 and 1954 single story construction uses a combination of non-ductile reinforced concrete columns, discontinuous reinforced concrete walls and timber. The subsequent construction uses a combination of reinforced concrete walls and non-ductile columns, steel columns, steel beams, steel joists, concrete floor slab with steel panel, and steel panel roof.

Of most concern is the prevalent use of non-ductile reinforced concrete columns along the exterior of the building. These columns were designed to take lateral forces in bending. The columns are non-ductile as they have only #2 stirrups (possibly not well hooked to the vertical bars) at 12-inch spacing, further aggravated by low concrete walls at grade that make the columns "short". Figure 2-4 shows an aerial view of the building, highlighting the southwest corner of the building that is weakest. Figure 2-5 shows the typical exterior, highlighting the non-ductile "short" columns used along the perimeter of the building.

Most of the classroom areas in the 1952 and 1954 construction incorporate a "monitor" level above the main classroom areas. This monitor level provides attic space and second story level windows. It is built using heavy glulam, post and beam wood construction, using a 3x6 straight sheathing for the roof system. The break in the roof diaphragm caused by the monitor level substantially weakens the seismic load-carrying capacity of these portions of the building. Figures 2-6 and 2-7 highlight the weaknesses.

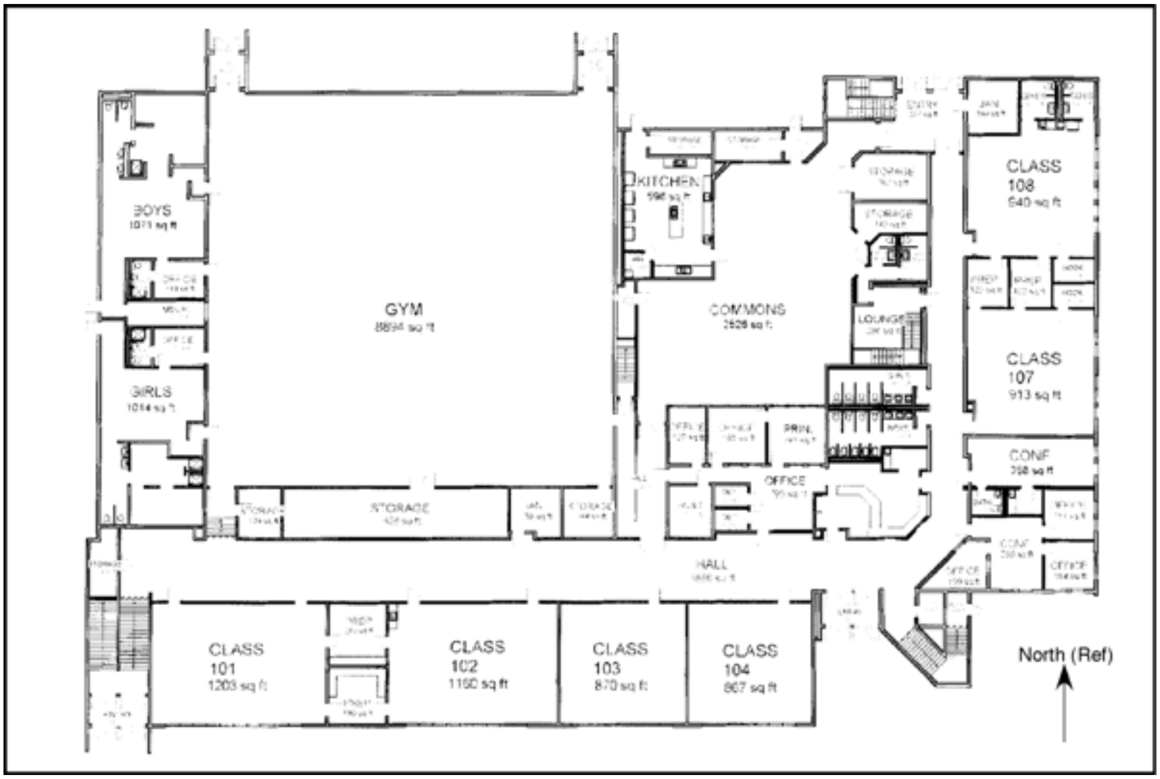

Figure 2-2. Plan of Lower Level – Gym and East Additions

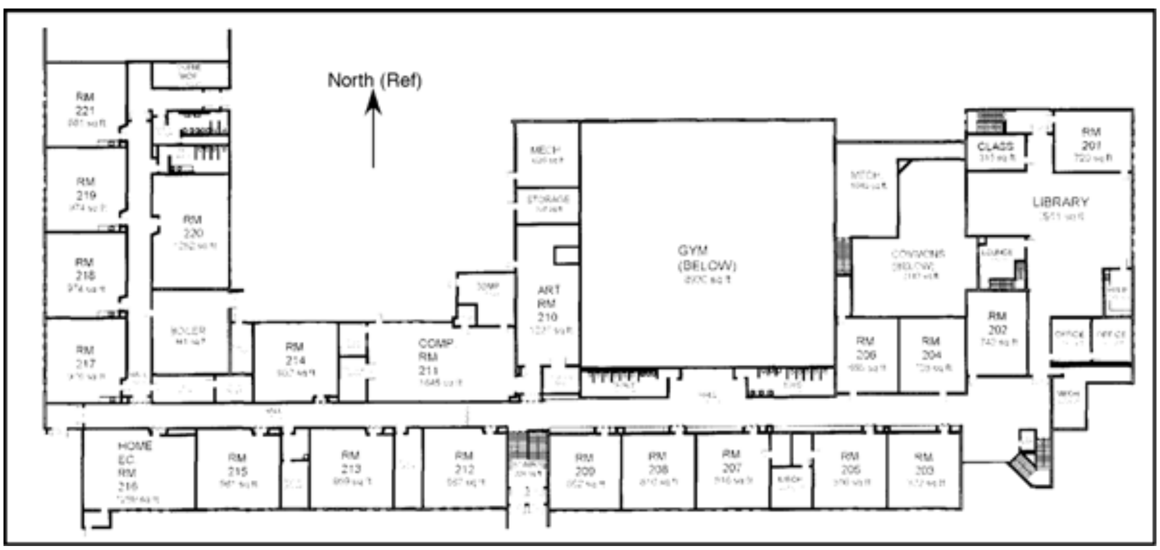

Figure 2-3. Plan of Upper Level – Gym and East Additions; and Original 1952 Building

Most of the current east, south and west facades, as well as limited portions of the other facades, use a combination of reinforced concrete footing wall, short reinforced concrete columns through a window level, and then a reinforced concrete wall up to the roof level. The reinforced concrete columns (Figure 2-5) use #2 bars as ties at 12-inch spacing.

While this type of column detail was commonly used prior to 1970, experience in past earthquakes now shows that this type of column is non-ductile, and the short column effect caused by the window configuration further aggravates the ductility demand on the columns under sufficiently large earthquakes.

Figure 2-4. Aerial View of Building, Highlighting Weakest Portion

Figure 2-5. Middle School South Elevation (1952 Section)

We evaluated the older portions of the building to determine its capacity to withstand seismic loading. The most severe weakness is the limited strength available by the outside reinforced concrete columns (open arrows, Figure 2-6); severe damage is expected to start at PGA = 0.22g. An earthquake with PGA = 0.27g would be large enough to result in gross x-type cracking through most outside short columns, including severe distortions of the roof system. Once the outside columns crack, they have almost no ductility capacity to absorb drift while maintaining column integrity; concrete will spall and the vertical bars will buckle. Compounding this problem is that in the older parts of the building, the monitor level style of construction has essentially no roof diaphragm capability to transfer seismic wall and roof loads to other lateral force resisting system members. Figure 2-7 highlights that the existing 3x6 roof sheathing is discontinuous mid-way through the classrooms, and that the interior 4-inch concrete walls are not continuous to the roof level. The gypsum board walls that form the classroom dividers are weak (limited nailing and limited capacity by the gyp board), and the "wind bracing" from the attic level 6x10 beams use only light nails to transfer load. Considering the limited ductility available, we estimate short column failures and collapse at PGA = 0.45g, possibly somewhat less should the earthquake be a long duration subduction zone (like a M 8.5+ event with epicenter immediately offshore of Kodiak Island.

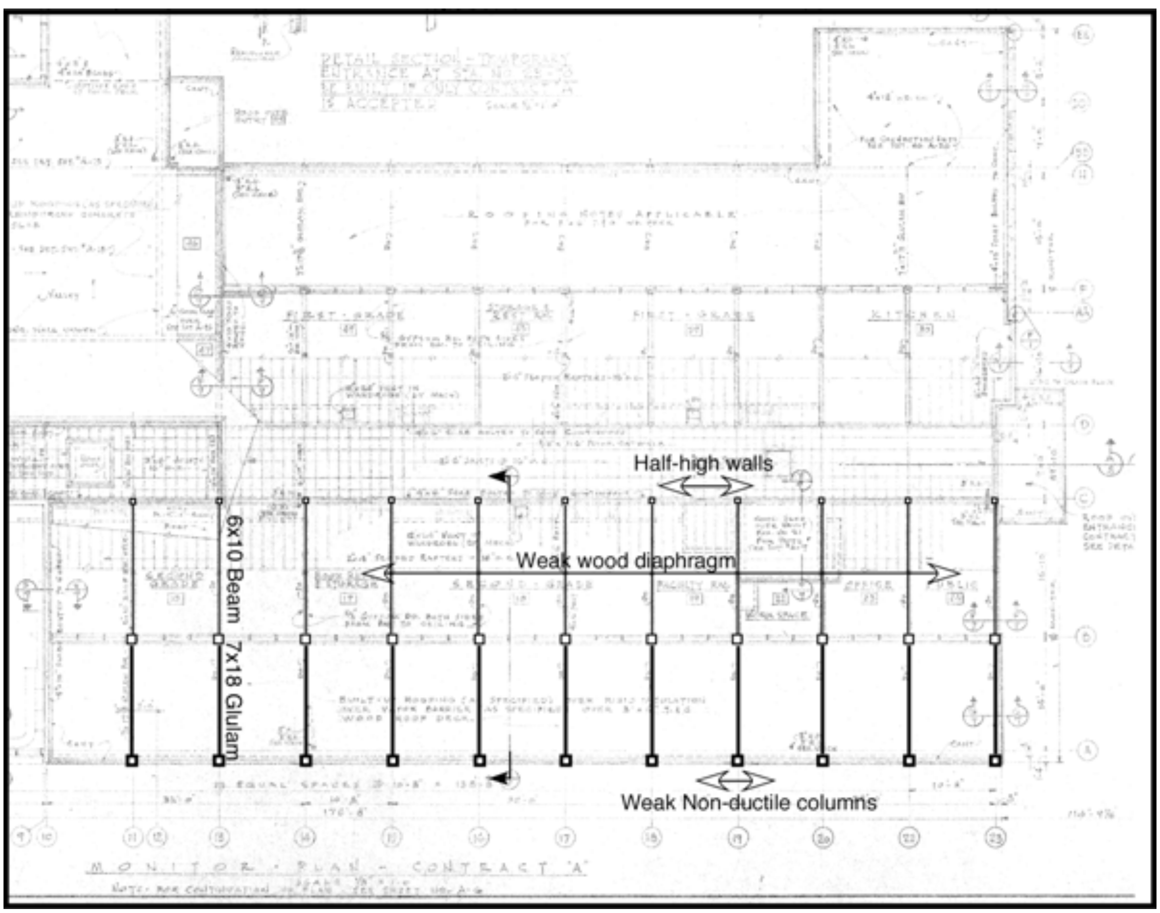

Figure 2-6. Middle School Plan, Highlighting Structural System (1952 Section)

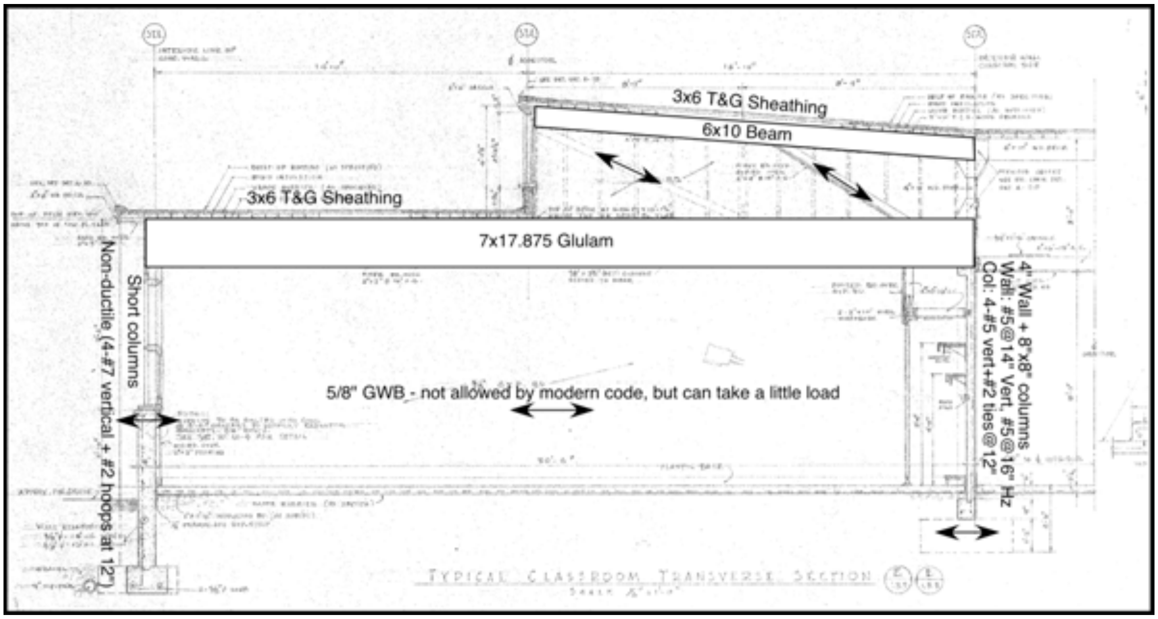

Figure 2-7. Middle School Cross Section (1952 Section)

Summary. The weakest part of the building is the existing old 1952 wing and adjacent 1954 classrooms that use the same style of construction. These portions of the building use non-ductile reinforced concrete columns (typical vertical steel is 4 -#7 bars, with #2 stirrups at 12 inch spacing), aggravated by short column effects. Also, these portions of the building have no roof diaphragm system owing to the discontinuous monitor / attic level, and lack shear walls that extend to the roof level. To a lesser extent, similar exterior short column issues occur on the eastern two-level portions of the building, and allowance for adding some shear walls along the weak column lines in those portions of the building is provided in the suggested upgrades. Section 4 describes the recommended upgrades.

2.3 High School Library Wing

The Kodiak High School (KHS) includes several buildings constructed at different times: the Vocational School (East and West Wings, built 1966), the Gym and Pool (built 1972); the Mat Room (built 1995), and the Library Wing (built 1972) and the Kitchen (built 1993).

The Kodiak High School (KHS) buildings are located at the Mill Bay Complex. Figure 2-8 shows an aerial view of the buildings. For purposes of this report, the Kodiak High School includes all the structures within the heavy red lines in Figure 2-8.

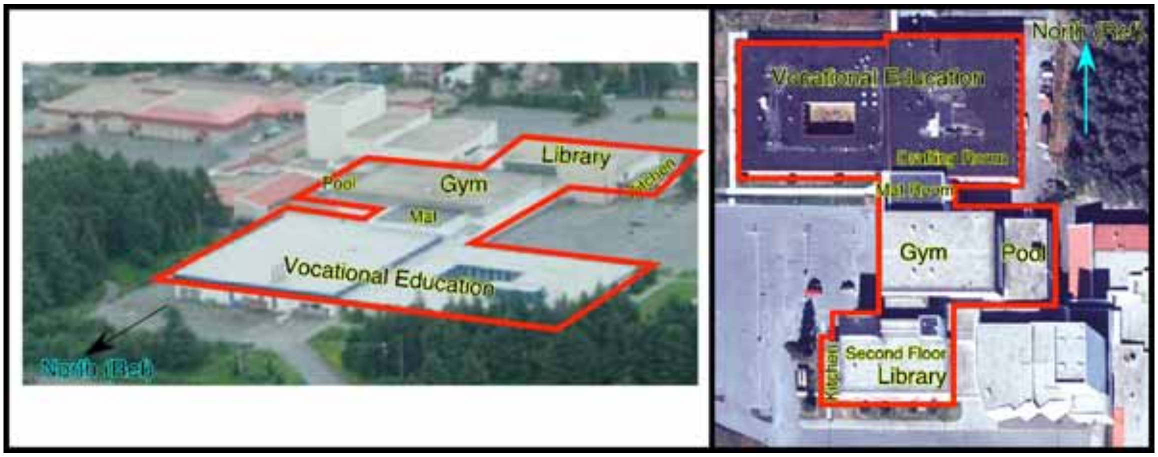

Figure 2-8. High School Facilities

The High School complex as currently built was constructed over a 39 year time frame, with various additions and alternations made in that time frame. The following highlights the various parts / additions to the High School complex. The scope of the various additions and alternations as they relate to seismic performance of the High School complex are further described in Section 4.2.

The Vocational Education portion has a gross area of about 58,767 square feet. It was originally built in 1966.

The Gym – Pool – Commons - Library portion (Figure 2-9) has a gross area of about 35,674 square feet. It was originally built in 1972. The pool was replaced in 1982. The Gym area was upgraded for handicap access and basic upgrades in 1988. The bathrooms in the Library wing (first floor) were upgraded in 1991. The Gym was altered in 1992. The kitchen was added to the west edge of the library in 1993. An outside entranceway was added in 1994 to the east side of the pool.

The Gym, Pool Commons and Library wing were designed in 1972. Design loads were: UBC Zone 3 (1970 edition). The concrete masonry units (CMUs) were filled where reinforced and left void where not reinforced; the steel decks were designed to act as diaphragms.

The library section is steel column with CMU infill walls. Figure 2-9a shows the plan of the lower floor (including the gym and pool) and Figure 2-9b shows a larger scale plan of the second floor.

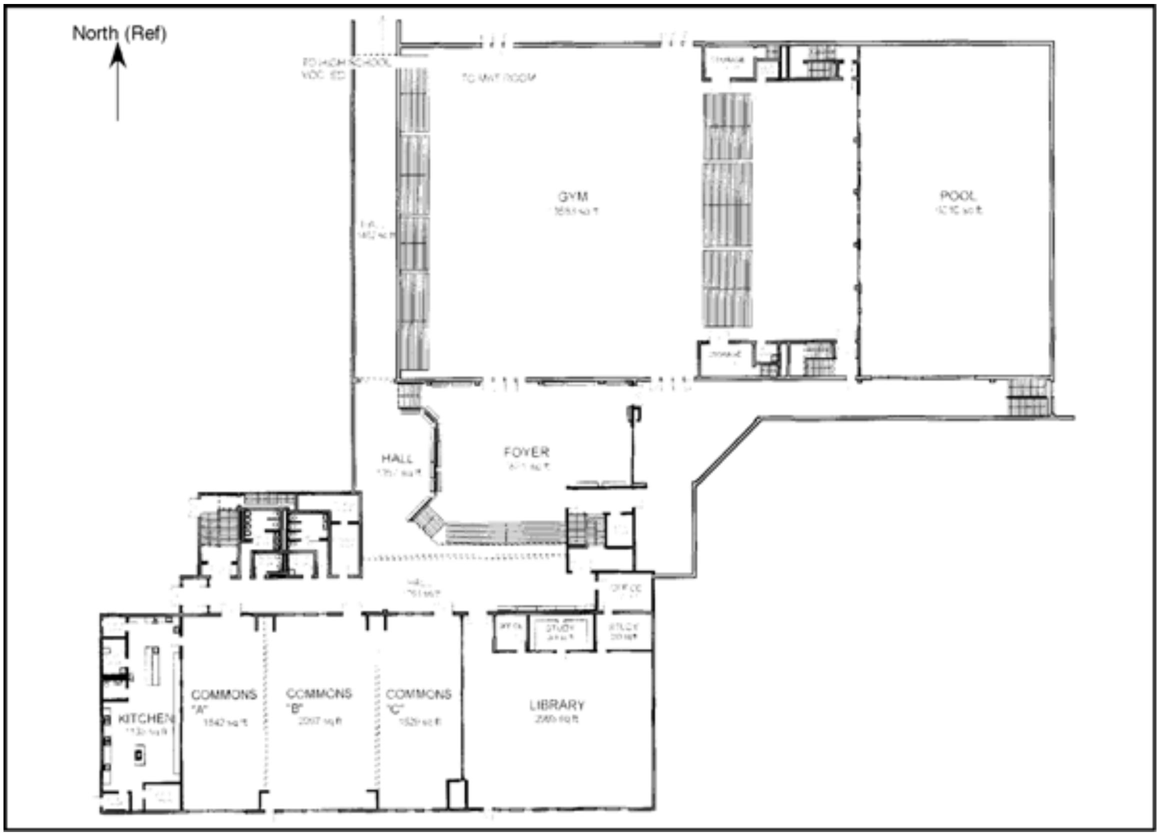

Figure 2-9a. Plan of Gym, Pool and Library

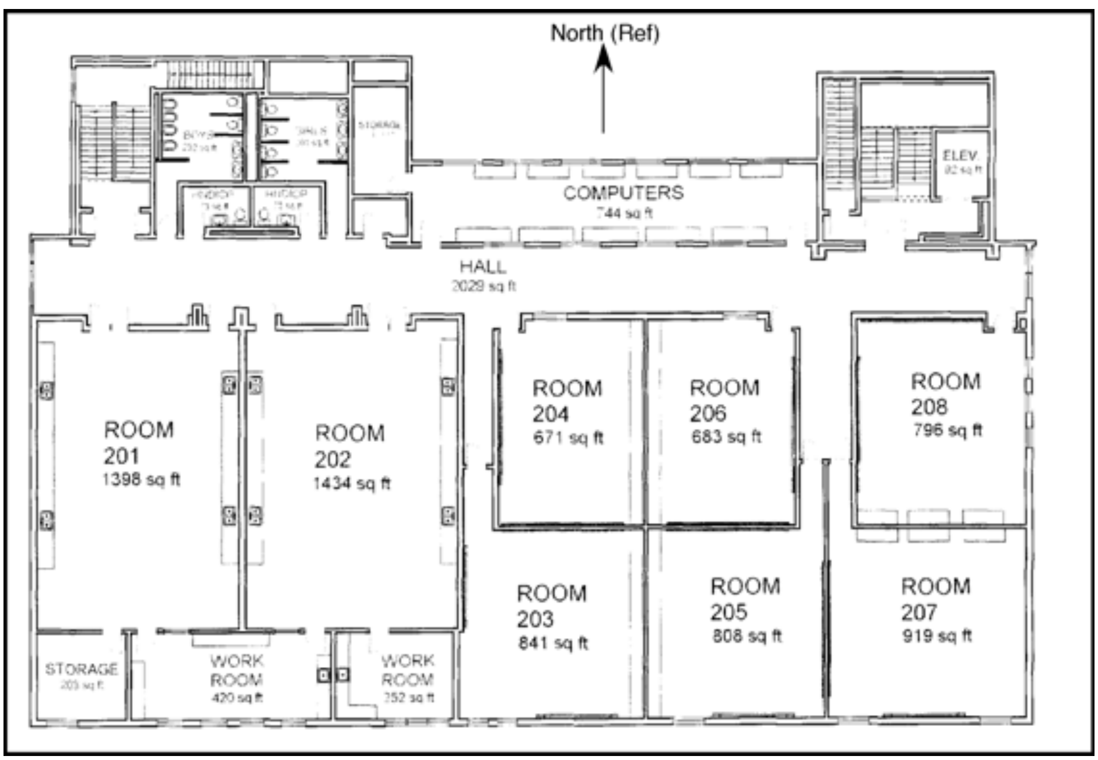

Figure 2-9b. Plan of Second Floor, Library Wing

Figure 2-10. Aerial View of High School Complex, Library in Foreground

The library structure is seen in the foreground of Figure 2-10. It is two stories tall, and rectangular in plan, 60 feet (north-south) by 132 feet (east-west). The small one story structure observed in Figure 2-10 to the west of the Library wing is an independent steel moment frame structure, and is seismically adequate.

The roof and second floors of the library wing are 2.5 inches of reinforced concrete slab supported by 1.5 inches metal ribbed pans. The concrete floors are supported by interior steel wide flange beams, which in turn are supported by built up steel plate girders along the edges of the building. The girders are supported by W14 steel columns along the perimeter of the building.

On the north side of the library wing are two towers, called "Core A" (west side) and "Core B" (east side) (see Figure 2-11).

A code-based seismic evaluation was initially performed assuming the building is a ductile moment frame. This code-based evaluation *ignores* the torsional impacts caused by the Core A and Core B towers, and those impacts are described later. The seismic loading is applied assuming the building responds as a steel moment frame in the east-west direction, and in the north-south direction, the Core A and B will act to resist the lateral seismic loads. Using a code-type formula base shear of V=0.14W (probably the basis in 1970 when the building was designed), the columns are stressed to 88% of their nominal code-based capacity for combined axial and bending moments. It would appear that this was the design approach for the building.

Figures 2-11 and 2-12 show the key elements of the load path for seismic loading in the east-west direction. The main part of the library has 14 wide flange steel columns, all oriented to provide the strong axis strength for loading in the east-west direction. As described above, if the reinforced concrete Core A and Core B towers are neglected from the analysis, the columns are nominally adequate to meet the 1970 code based design of V=0.14W. However, review of the drawings clearly shows that the first floor and roof elevation floor/roof diaphragms are continuous to the Core A and Core B concrete towers, so the building will in fact not behave as the simplified code analysis would suggest. Instead, for east-west loading, the Core A and Core B concrete towers will act as stiff walls, and cause the columns along line 18 (southernmost line) to have more drift (and load) than a balanced stiffness design would assume. The substantial torsion response will also attract a lot more load to the Core A and Core B towers than would have been assumed neglecting the effects of torsion. Figures 2-13 and 2-14 show some of the cracks that have already formed in Core A, likely due to prior earthquakes (PGA = 0.1g or so at this site), strongly indicating that the steel within the walls has already yielded in past earthquakes. Six separate visible cracks (about 1/16 inch) have already formed in these walls. This confirms that the walls will be greatly overloaded in earthquakes with PGA = 0.47g (475 year return period) or higher, and that weaker elements of the Core (spandrel beams over openings) will be severely racked in such events.

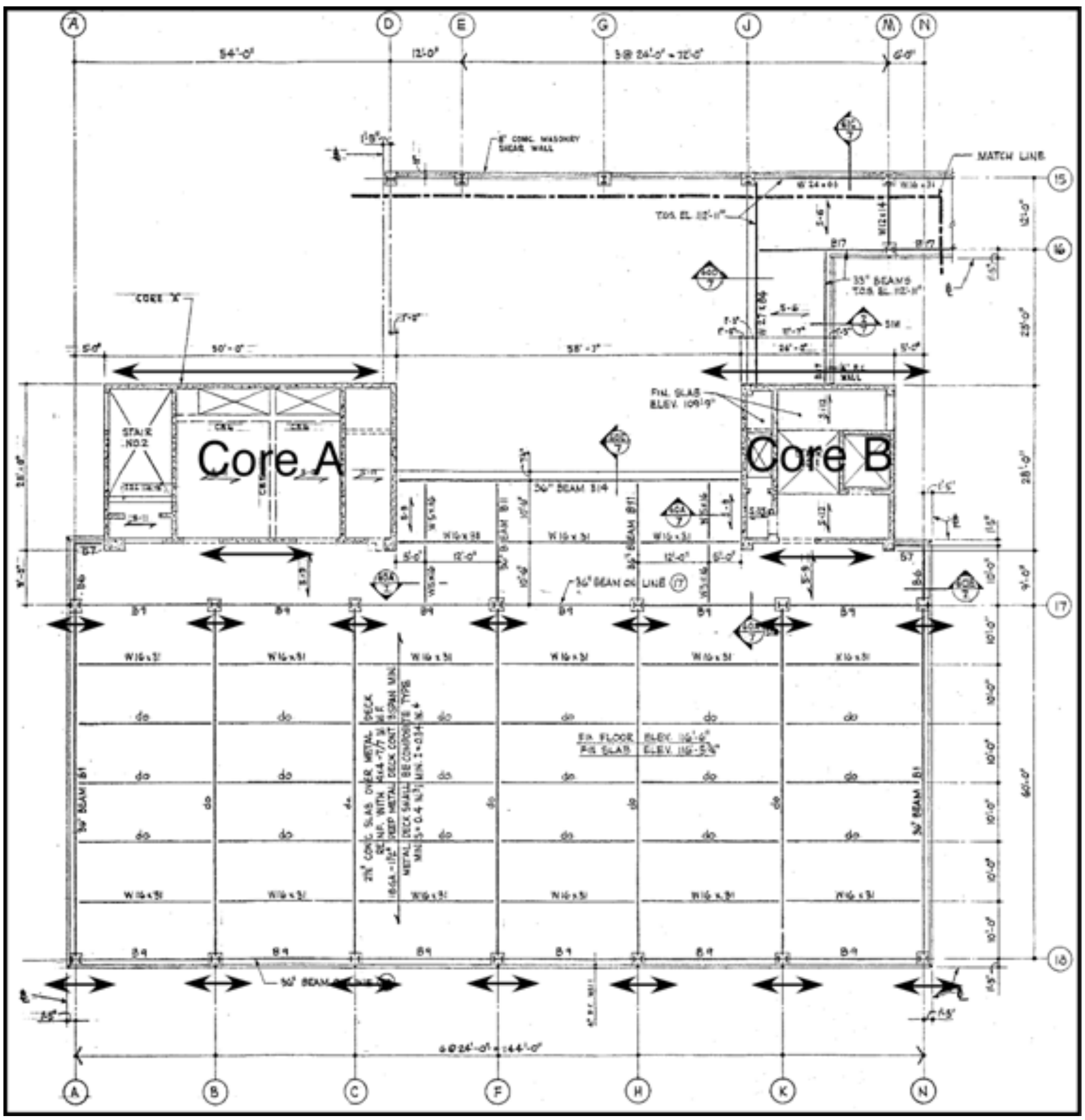

Figure 2-11. Seismic Load Path, East West Loading, Library (Plan)

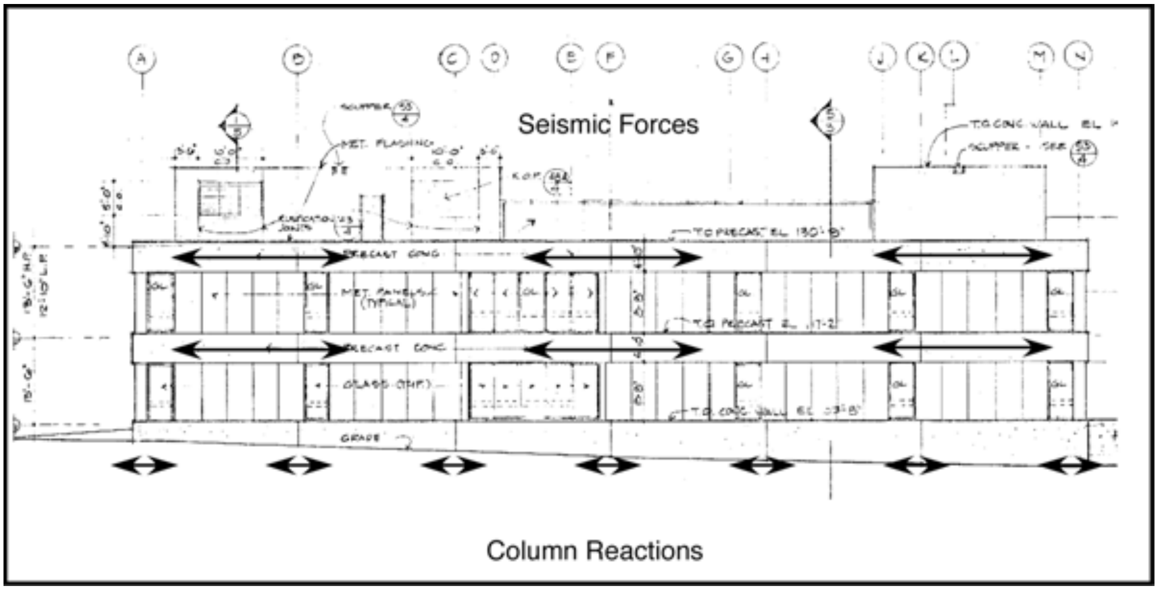

Figure 2-12. Seismic Load Path, East West Loading, Library (Elevation)

In the north-south direction, the reinforced concrete shear walls in the Core A and Core B towers provide the primary lateral seismic load path, with residual capacity of the steel column frame action that would begin to work only if the shear walls become overloaded. The building appears well balanced for resisting loads in the north-south direction.

Figure 2-13. Column-Spandrel Cracks in Core A Above Door and Below Window

Figure 2-14. Shear Wall Cracks on North Wall of Core A

Much has been learned about the performance of steel moment frame structures since 1970, and there are other factors which suggest that the Library building might not be as robust to resist seismic loads in the east-west direction as was likely originally intended in 1970. Experience has shown that many types of moment-connections in steel structures are not as ductile as once assumed. For the most part, this building does not particularly use the brittle-type moment connections commonly used since the mid-1980s and commonly fractured (about 20% of all steel moment frame connections cracked in buildings exposed to PGA > 0.4g) in the 1994 Northridge earthquake. Most of the moment connections in the Library Wing are made from bolted angles that connect the beams to the columns, and these can probably take quite a bit of distortion beyond yield.

However, there are three remaining factors that make this building somewhat weaker than desirable:

- There are only two lines of column frames that can resist east-west seismic motion. Damage to any single column will start to overload the remaining columns, so there is not much reserve capacity in the building.
- The beams (built up plate girders, 36 inches deep) are much stronger in bending than the columns. Thus, the building is exposed to "strong beam / weak column", a design flaw that was largely unknown in 1970. With this strong beam / weak column type of construction, the columns yield in strong earthquakes well before the beams, and thus the columns take up most of the damage. With sufficient yielding, the columns will possibly buckle, leading to possible collapse. In

modern steel frame construction, the objective would be to use strong column / weak beam, so that damage will accumulate in the beams and not the columns, thereby limiting the potential for damage to the main load bearing components of the building.

- The structural evaluation analysis performed herein assumed that the building will behave as a regular rectangular load resisting system, when loaded in the east-west direction in earthquakes. This neglects the stiffening effects of Core A and Core B at the north end of the building. Cores A and B will act to induce torsion into the structure, thereby reducing seismic loads on column line 17 (good for those columns), but increasing drifts and loads on column line 18 (south façade) (bad for those columns). Given that the columns on line 18 are already loaded to near their limit assuming 1970-base code loads, this further reduces the safety margin for the building.

2.4 Ouzinkie

The Ouzinkie School serves the village of Ouzinkie. Figure 2-15 shows an aerial view of the school, with the south façade in the foreground.

Figure 2-15. Ouzinkie School (West to the left in this photo)

The current school was built in several stages.

The central portion of the school is the original construction, designed in 1969. This portion includes classrooms and a multi-purpose gym (since converted to classroom use). The exterior walls use 0.5 inch plywood, with unspecified nailing. The roof uses plywood with unspecified nailing. The ground level wood floor is supported by wood beams, which in turn are supported on 6x6 wood posts to small footings resting on the rock-like foundation (Figure 2-16). There are no cross bracing members or shear walls that provide load path continuity from the first floor to the foundation shown on the original drawings; nor were any observed in the field. The exterior walls shown in Figure 2-16 show insulation, with exterior cladding not connected to any foundation at all.

Figure 2-16. Crawl Space Under Central Section (1969 Portion) of Ouzinkie

The western half of the building was designed by a different architect in 1979. In that design, a two-level gym and a one level classroom section were added. The style of construction is timber with plywood walls and wood floor. The floor is supported on 6x6 timbers to individual small concrete footings. The drawings call for 3x6 diagonal bracing to carry the seismic loads from the first floor to the foundations, using 4-inch split rings to provide high shear capacity load transfer. Checking the foundation for V=0.183W (code seismic design basis for 1979), this portion of the building appears adequate as designed.

The eastern third of the building was design in 1994. The foundation system for this portion of the building uses 6x6 wood posts on small foundations with steel tie rods to provide lateral load path. The foundations use rock anchors to provide resistance to uplift under high seismic loads. This section of the building appears adequate for seismic loads.

To the far east end of the site is a small building used to house the generator for the school (Figure 2-17). This small building has no foundation and is highly susceptible to movement under strong ground shaking. If the building moves, it will likely break fuel lines and other utilities that enter the building.

Figure 2-17. Emergency Generator Building Foundation

2.5 Peterson

The Peterson school is located at the Coast Guard base, adjacent to the airport in Kodiak City. In the 1964 earthquake, tsunami waters flooded a portion of the airport, and came within about ¼ mile of the school grounds. The then-existing building was not known to be damaged (local PGA estimated at about PGA = 0.10g). The Coast Guard since turned over ownership and operation of the school to KIB.

As can be seen in Figure 2-18, the school is located in a flat area. Old Womans Mountain is the mountain seen immediately to the right of the school. The soils beneath the school are characterized in WLA (2006), described as dense to very dense gravelly sands, with a soil-to-rock profile suggesting that the school overlies a V-shaped filled-in gully.

Over the years there has been a number of additions to the Peterson school.

The oldest portion of the Peterson school was built circa 1946. This portion is a single story structure, rectangular in plan. A central corridor runs down the long length of the building, with the roof supported on 6x6 wood columns at either side of the central corridor, and by 5I10 steel columns at the two edges of the building. The roof system is composed of 0.5 inch plywood (unknown nailing) atop wood joists supported on glulam beams. In the transverse direction of the building, steel diagonals are used between classrooms to provide some measure of a lateral load path, only designed for wind loads.

In 1956, two classrooms were added to the north end of the school. These two classrooms were constructed with reinforced concrete walls running in the east-west direction and glass block and glass window walls running in the north south direction.

Figure 2-18. Peterson School (behind runways)

In 1966, an addition was made at the southeast end of the building. For this addition, the roof uses a 1.5-inch deep metal deck and is supported on steel joists. Exterior and interior walls are tall (18.3 feet), and are typically 8-inch thick reinforced masonry with one #5 vertical at 32-inches on center and one #5 horizontal at 48-inches on center, plus bond beams at the top. Additional steel was placed around all door and window openings. Masonry units are filled solid where reinforced. This portion of the building was designed per the 1964 UBC per seismic zone 3 requirements.

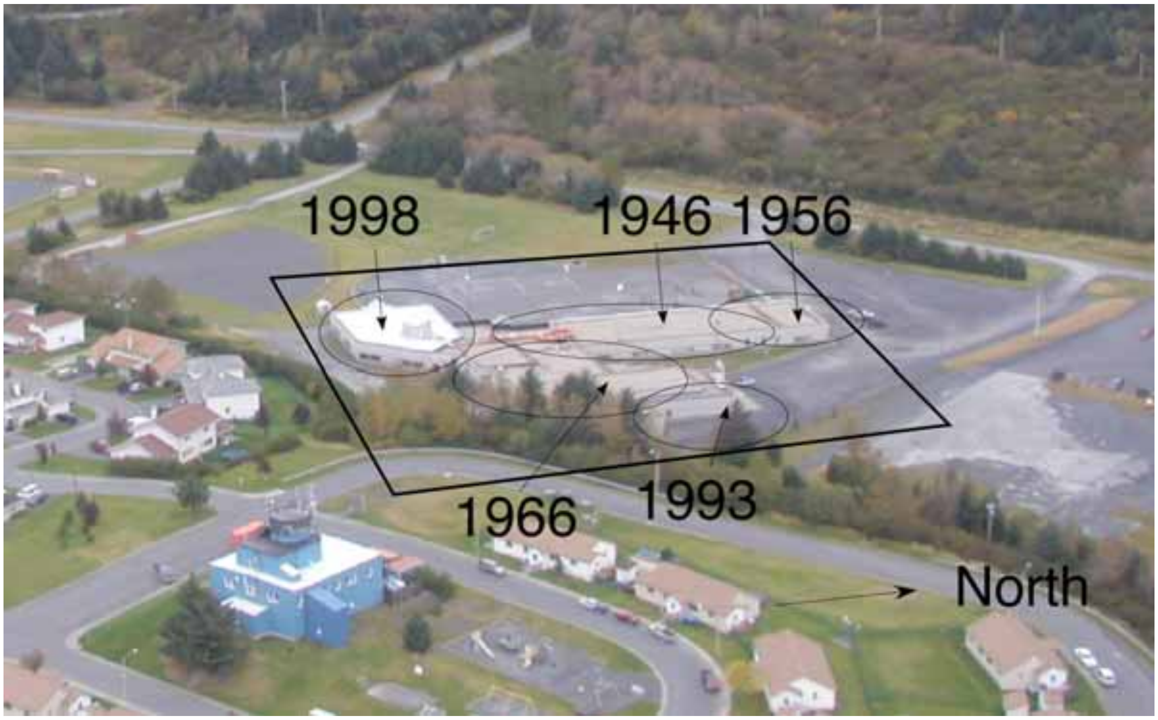

Figure 2-19. Peterson School

In 1975, a small building was constructed adjacent to the main building, serving as the boiler house for the facility. It is a reinforced masonry building, 30 feet x 20 feet in plan dimension.

In 1986, repairs were made to the 1946 building. In the north-south direction, the exterior full-wall length windows were removed, and new windows were installed, along with new reinforced CMU wall elements to fill in the space of the original windows.

In 1993 a new wing was added at the east side of the building. It was designed per UBC 1991, zone 4. It is a reinforced masonry building. All masonry units with reinforcement or metal inserts were filled solid. The roof is a metal deck, welded to inserts in the masonry walls. In this addition, the suspended ceiling uses compression struts with diagonal tie wires. In 1993 a similarly seismically-designed suspended ceiling was installed throughout the 1946, 1956 and 1966 portions of the building.

In 1998 an addition was constructed at the south end of the building including a penthouse section. This portion of the building was designed per UBC 1994, zone 4 seismic requirements (V = 0.138W). The roof sheathing uses 5/8" plywood, wall sheathing is 0.5-inch plywood and floor sheathing uses 0.75-inch plywood. Diaphragm nailing was 6-inch at plywood edges (3-inches at some walls), with 8-inches or 10-inches at intermediate locations.

With the exception of the 1946 north portion of the building, all additions have clear lateral force resisting systems. While none of the more modern sections have substantial margin over and beyond their original design bases, they should all perform reasonably for earthquakes up to PGA = 0.3g to 0.4g. Assuming that the site can be classified as "rock" (or thin layer of stiff soil over rock), the current understanding is that the 475-year return period earthquake would have PGA = 0.47g, and design of a new building at this site per IBC would use (about) PGA = 0.56g as the design basis. With these factors in mind, there might be some benefit to upgrade the 1966 portion with the tall masonry walls for an increased level of seismic forces, but this has not been explored.

After consideration for all the additions, of most concern is the seismic capacity of the original 1946 building.

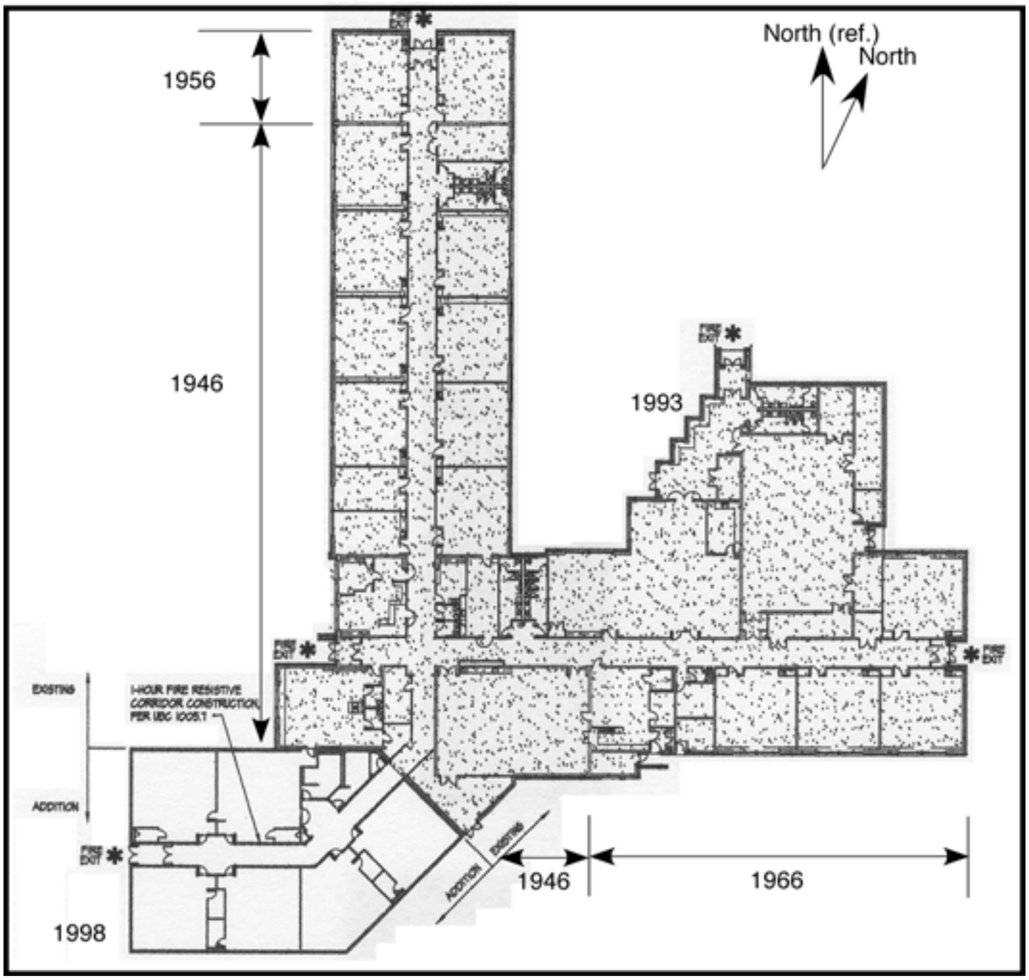

Figure 2-20. Peterson School

Figure 2-21 shows the critical cross section through the classroom walls in the 1946 portion of the school.

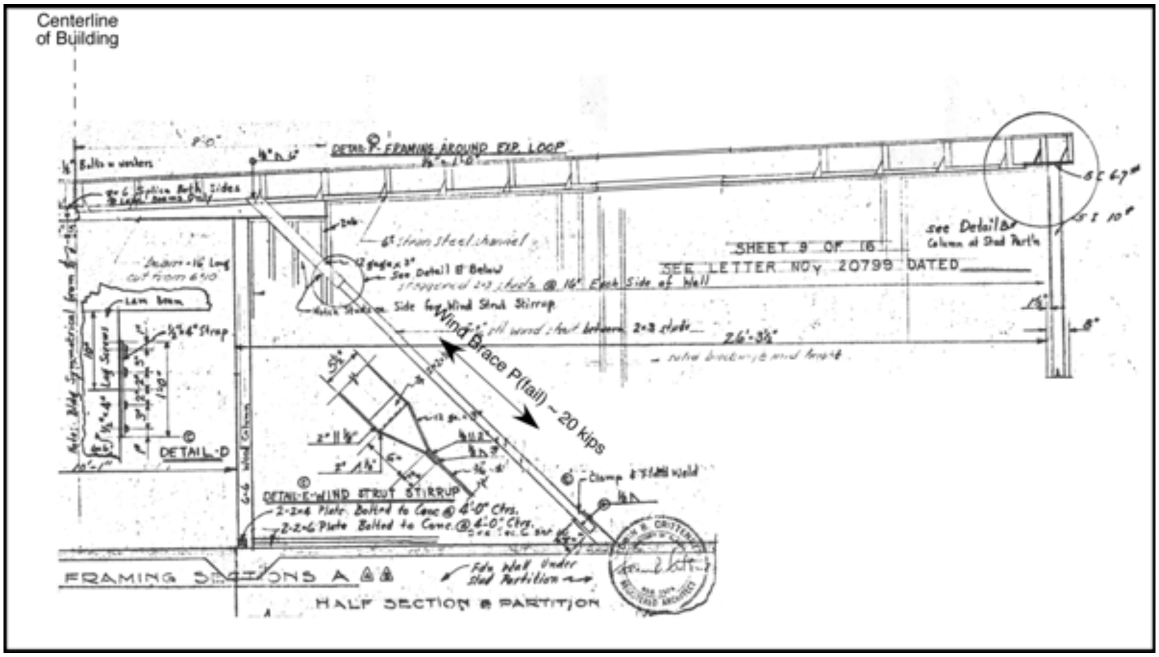

Figure 2-21. Cross Section Through Classroom Wall (Typical for 1946 Section)

The only lateral load resisting element in the east-west (transverse) direction of the 1946 building is the "wind brace". There are two 0.5" gypsum boards acting as sheathing on 2x3 wood studs that form the partition walls between the classrooms, but these have little if any seismic capacity and uncertain nailing schedule. This wind brace is made up of a 3/16" x 3" piece of steel, welded at several connection points with 1/8" thick welds, and then connected to a 6" steel channel (collector) at the roof level, and then connected (uncertain on the drawings) via straps to the 4" concrete slab on grade. This element can take tension loads only. The three sets of welded connections along its length cannot be relied upon to be "ductile", as there are large stress risers at each discontinuity. Even so, the nominal yield strength of the wind strap is likely at least 15 kips, more likely about 17 kips, and could be as much as 20 kips. Assuming that the entire roof weight for two classrooms (one either side of the central corridor) must be taken by one wind strap, and allowing no snow load at the time of the earthquake, and assuming there is a 50% margin above these values available, then the wind strap should break at PGA ~0.27g (assuming the original light weight 1946 construction). Once the wind strap breaks, then there is some residual strength afforded by the exterior wall columns (four 5I10), which in bending could take about PGA = 0.25g with ductile response and reasonable life safety assurance. Given the relative flexibility of the building elements, it is likely that the wind strap will take the vast majority of the seismic loads until it breaks, after which the 5I10 columns provide some margin. However, for PGA large enough to break the wind straps (about PGA = 0.30g), the remaining 5I10 will fail code levels at about the same PGA level. Thus, extensive damage is likely at PGA about 0.30g in the east-west direction.

In the north-south direction, the 5I10 columns at the outside of the walls will yield at PGA = 0.06g (very low). The question arises as to whether any of the north-south running walls can take seismic lateral loads. As can be seen in Figure 2-22, there are stucco exterior walls covering about half the length of the outside walls. The original

1946 drawings show that there were windows running completely along this wall, with glass block walls above the windows. The stucco siding was added over the original glass blocks as part of the 1986 re-model of the building. Under the stucco are partial height masonry units, reinforced with #4 bars at 32 inches vertically, but these block walls were not continued all the way up to the roof diaphragm level. Instead, these walls are lightly attached to the original steel angles that formed the boundary elements above the old windows; there is no documentation to show that these angles were originally installed in a manner to act as collectors, so the force resisting system to take north-south loads from the roof level into these new reinforced masonry walls is uncertain.

Figure 2-22. North South Exterior Wall. Photo taken looking south, 20 feet from north edge of building

With the 1986 renovation of the outside masonry walls, as well as new built-up roofing, the weight of the building was increased by about 80%. In its current configuration, the outside masonry walls can take some east-west loading (acting as cantilevers). The current building should remain elastic up to PGA = 0.10g and should provide reasonable life safety assurance up to PGA = 0.25g.

2.6 High School Gym Fan Room Walls

The High School Gym structure is rectangular in plan, 156 feet (east-west) by 120 feet (north-south). The structure is primarily a single story facility, with roof level 34 feet above the finished floor level. Figure 2-10 shows an aerial view of the building as part of the entire High School complex. Figure 2-23 shows the exterior north wall of the Gym, with the lower level swimming pool facility just at the bottom left of the photo.

Figure 2-23. Gym, North Façade, Pool (far left), Mat Building (right),

The roof diaphragm is 1.5 inch deep metal decking. The roof is supported on steel trusses, which in turn are supported on steel columns. Lateral loads are resisted by x- and chevron-braced steel frames located along the exterior walls of the building.

Precast concrete panels are attached to the north-south running trusses at the top level of the building (Figure 2-23). Below the top level precast concrete panels are lightweight metal sheathing panels that extend to the ground level.

The precast concrete panels are connected to the steel trusses using steel connectors. For dead weight, these connectors have a very large factor of safety (about 10). Under strong earthquake motions, the precast panel cladding will interact with the steel trusses and framing system, possibly resulting in cosmetic damage, but not a serious life safety concern.

The roof consists of a 20 gage (t=0.0359 inches) steel corrugated deck system. As originally designed, it consists of built up roofing over rigid insulation over a vapor barrier over a 1.5-inch deep corrugated steel deck. The steel corrugated deck acts as an in-plane flexible diaphragm to distribute lateral seismic loads to exterior trusses and framing systems.

For ground motions of about PGA = 0.4g (original design basis of the building), the x- and chevron braced frames should perform as intended, if one neglects the effects of the interior fan room non-structural masonry walls. Neglecting the strength and stiffness of these non-structural walls, the Gym should provide reasonably good seismic performance for code-basis design earthquakes. For somewhat larger earthquake (475 year motion PGA = 0.47g, per Table 3-1), the building might be somewhat overloaded, columns might lift and more damage than desired would occur, but this is a relatively rare event, and the cost to upgrade the building from PGA = 0.40g to PGA = 0.47g will be shown (Section 6) to be just marginally cost effective.

However, the above findings are somewhat optimistic, given that in fact there are a set of interior non-structural reinforced masonry walls that were installed to form two fan rooms in the Gym. Inspection of these walls within the gym shows that the two walls are already damaged, as can be seen by the telltale diagonal stair-stepped cracks in Figure 2-24. Similar cracks exist in the southeast wall. Figure 2-25 shows the plan of the gym at the roof level, highlighting some of the forces involved.

An evaluation of the building was performed to determine the likely cause of the cracks.

- First, an exterior inspection of the building foundations in this area was performed by geologists Bill Lettis and Rob Witter. While complete access to the foundation level was not available, observations near the building corners with these walls observed no particular distress or settlements. Further, as described in WLA (2006), the site is not prone to liquefaction or landslide or differential settlement. Thus, we rule out differential settlement as being the cause of the damage.
- Second, we considered whether strong winds might have caused the damage. Immediately outside, the building has a vertical change in elevation of 21.8 feet from the Gym roof to the Pool roof. Assuming an applied wind load of 40 psf, there would be about 105 kips applied to the wall. It is quite possible that the original structural engineer assumed that these wind loads would be distributed through the roof diaphragm to the exterior steel braced frame walls, and ignored that the two walls (heavy dashed lines in Figure 2-25) would take some of this load. Based on the relative location of the masonry walls versus the exterior steel braced frames, the masonry walls would probably take about 90% of the total wind load. The masonry walls are 8-inch with code minimum steel in the horizontal (#5 bar bond beam at 48 inches) and vertical (#4 bar at 32 inches) for a wall of this size. Only the cells with reinforcement were grouted. Thus, the wind load would apply a shear force to these walls which might have been unintended. If one assumes that the available steel in the wall governs, and takes no credit for any masonry strength, the wall could theoretically take about 144 kips, at which point large shear cracks would form in the wall. In practice, owing to limits on the foundation wall attachments and roof attachments, the walls are probably not quite this strong, possibly reaching first yield levels at half this level or so. Even with these considerations, a wind that produced an average pressure of 40 psf on

the east wall would not be quite strong enough to create yielding in the wall, assuming the vertical and horizontal steel were in fact placed as suggested on the drawings. Possibly, a stronger wind did occur, and that might have cracked the walls.

- Third, this building has experienced earthquakes in the past, probably on the order of PGA = 0.1g to 0.15g. Owing to the location and stiffness of these walls, the theoretical strength of each wall would be reached at PGA = 0.13g or so. Even though earthquake forces are two way (wind being one way), and the cracks only show in one way loading (as if wind was the loading mechanism), the earthquake loading might have caused the cracks, as in the reverse direction loading most of the seismic load would go to the exterior steel braced frames.

Figure 2-24. Non-Structural Wall Cracked, Northeast Corner of Gym

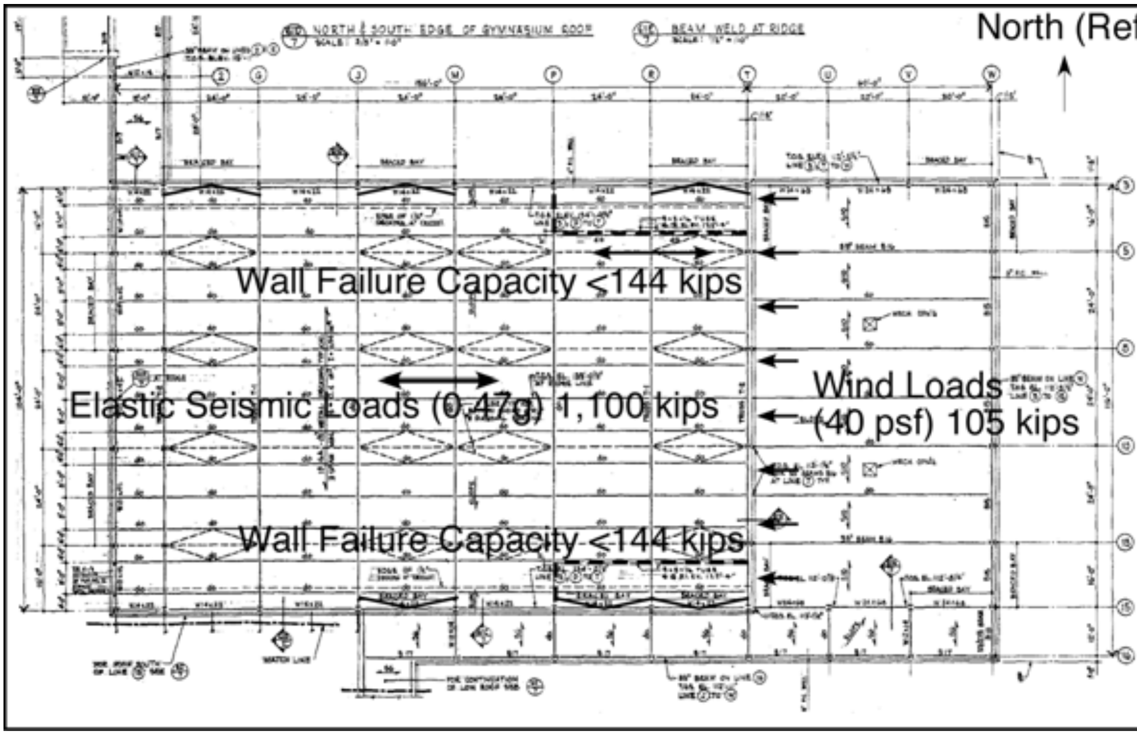

Figure 2-25. Plan of Gym at Roof Level

2.7 Non Structural Components

A walkthrough of all the schools was performed to assess the anchorage and restraint of important components of the schools. These components were then classified into several sub-categories: file storage cabinets that can topple; drink dispensers that are large and can roll / topple; large single annealed window (glazing) in hard putty in wood sashes in flexible buildings that will readily crack and produce shards; unanchored communication racks; sprinkler heads in weak suspended ceilings that can be readily damaged by the interaction between the sprinkler head and the ceiling system leading to inundation; desk top monitors that can topple; large kitchen items subject to toppling; medium and tall bookcases that can topple with life safety / egress issues in libraries and other locations; unanchored furnaces that can slide and break attached pipes; rod supported equipment that can sway sufficiently to credibly break attached pipes; floor standing electrical switchgear panels that are unanchored; unrestrained water and glycol storage tanks; vibration isolated generators or other rotating equipment that can readily fall off their isolation springs (needs snubbers); unanchored diesel fuel tanks that can slide and break attached pipes; unrestrained batteries for diesel generators; valuable counter top or rack mounted pieces of equipment that can readily slide and fall.

Table 2-3 summarizes the number of components to be upgraded (Table 6-2 further breaks down the type and cost of upgrades for each school). Also included are costs by building should all or portions of the existing suspended ceilings be upgraded. By "egress", it is meant that the ceilings are upgraded for seismic loads just at major exits and corridors. By "all ceilings", it is meant that the ceilings are upgraded throughout the building.

Building	Total Items, Except Ceilings	Total Costs, Including All Ceilings	Total Costs Ceilings for Egress Only	Total Costs, No Ceilings
	Items	Building	Building	Building
KBB Upper Level w/ south side	36	$102,042	$27,979	$3,292
KBB Lower Level	18	$51,164	$14,029	$1,650
Learning Center 1	36	$13,503	$13,503	$13,503
Vocational High Classrooms East+West, Gym, Pool	180	$367,600	$122,631	$40,975
Library wing two floors, plus common area	74	$161,708	$50,456	$13,373
Kitchen Addition	5	$12,390	$6,028	$3,908
Mat Room	17	$47,467	$13,015	$1,531
Auditorium	4	$11,238	$363	$363
Middle Corner 1952 Original	18	$35,616	$13,866	$8,428
Middle Addition 1954 Gym Area	6	$22,294	$5,981	$544
Middle 1959 North Classroom Addition	4	$16,675	$5,800	$363
Middle 1962 North Addition	8	$11,963	$6,525	$1,088
Middle 1962 East Addition	6	$27,731	$11,419	$544
Main Elementary	61	$84,281	$29,906	$13,594
East Elementary Original	103	$194,017	$105,293	$75,718
East Elementary	14	$38,118	$10,452	$1,230
East Elementary	23	$63,503	$17,412	$2,048
Northstar Elementary	31	$14,319	$14,319	$14,319
Peterson Elementary	38	$14,138	$14,138	$14,138
Chiniak	53	$70,985	$39,657	$29,214
Old Harbor Old Gym	3	$8,428	$2,991	$272
Old Harbor New Classroom School	35	$17,763	$17,763	$17,763
Akhiok	45	$39,966	$29,091	$20,934
Karluk	49	$42,231	$31,356	$23,200
Larsen Bay	58	$53,831	$32,081	$32,081
Port Lions	39	$12,234	$12,234	$12,234
Ouzinkie	27	$13,141	$13,141	$13,141
Total	990	$1,551,063	$664,147	$359,446

Table 2-3. Non Structural Items to be Upgraded and Costs

3.0 Seismic Hazards

Given the occurrence of an earthquake, there are four hazards that might occur: ground shaking, liquefaction (and related types of ground failure), landslide, and surface faulting. These hazards are further described below:

- Ground shaking hazard. Section 3.1 summarizes the ground shaking hazard for each KIB school.
- Liquefaction, Landslide, Surface faulting and Tsunami. Section 3.2 summarizes these hazards for each KIB school.

3.1 Ground Shaking Hazard

The Island of Kodiak is exposed to earthquakes from three sources. A comprehensive treatment of these sources is provided in a separate report prepared by William Lettis and Associates (WLA 2006). A summary of the sources and their potential for ground shaking is as follows:

- Interplate earthquakes. The Aleutian Trench subduction zone, source of the Great 1964 M 9+ earthquake. The 1964 earthquake was in interplate earthquake, with fault rupture denoted by the dotted line (1964 rupture area) in Figure 3-1, and the thick black line in Figure 3-2. It is now understood that the amount of slip that occurred under Kodiak Island in 1964 event was much less than under Price William Sound, meaning that the level of ground shaking on Kodiak Island was likely a lot less than it was near Prince William Sound. Except for the tsunami, the effects of the 1964 earthquake in Kodiak Island were relatively modest (only sporadic damage due to ground shaking). Both the original Peterson school (1945) and Middle school (1952) were constructed at the time of the 1964 earthquake, and neither was known to be damaged. Structural calculations suggest that the Middle school should have started to be seriously distressed at ground motions much above PGA = 0.2g, so this suggests that the 1964 earthquake likely produced ground shaking levels in Kodiak City on the order of 0.1g or so. A future rupture of this fault under Kodiak City is likely to produce much stronger ground motions, averaging PGA = 0.3g, but at some locations with PGA over 0.5g.
- Intraplate earthquakes. Intraplate earthquakes occur within the deeper Intraplate (Benioff) source. For example, the 1999 earthquake under the southwest part of the island occurred on a fault within the subducting zone, as denoted by the near vertical line and star symbol in Figure 3-2. Depending on the location and magnitude, the level of ground shaking at the surface of the island directly above the fault will commonly be in the range of 0.2g to 0.5g from large Intraplate events.
- Crustal earthquakes. Figure 3-3 shows a map of Kodiak Island, with locations of crustal faults shown. The Narrow Cape fault, located parallel to the southeastern edge of the island, is active and capable of producing earthquakes in the M 7 to M 7.5 range. The Chiniak school is the KIB school closest to the Narrow Cape

fault. Should this fault break with a M 7+ event, it will produce ground motions, on average, near PGA = 0.6g at Chiniak, at about 0.25g in Kodiak City (with variation of ±50% of these values). The Kodiak Island Fault (KIF) zone is shown as a solid black line, within the area that is mapped as Kodiak Island Area Source. There is currently ample evidence that earthquakes producing very high accelerations (PGA over 0.4g) have occurred repeatedly over the last 10,000 years or so in the area bounded by the red dashed lines. There may be multiple crustal faults in this region, of which the KIF is one. Should the KIF break with a M7+ event, along the center trace as mapped in Figure 3-3, ground shaking in Kodiak City will be about 0.5g ±50%, or perhaps 5 times stronger than what was felt in the 1964 earthquake. A M 6.5 or higher earthquake occurring directly at Kodiak City would produce ground shaking at most of the schools in Kodiak City with PGA about 0.65g (±50%), and would represent the worst possible earthquake in terms of producing high level of ground shaking at the greatest number of schools in the KIB system.

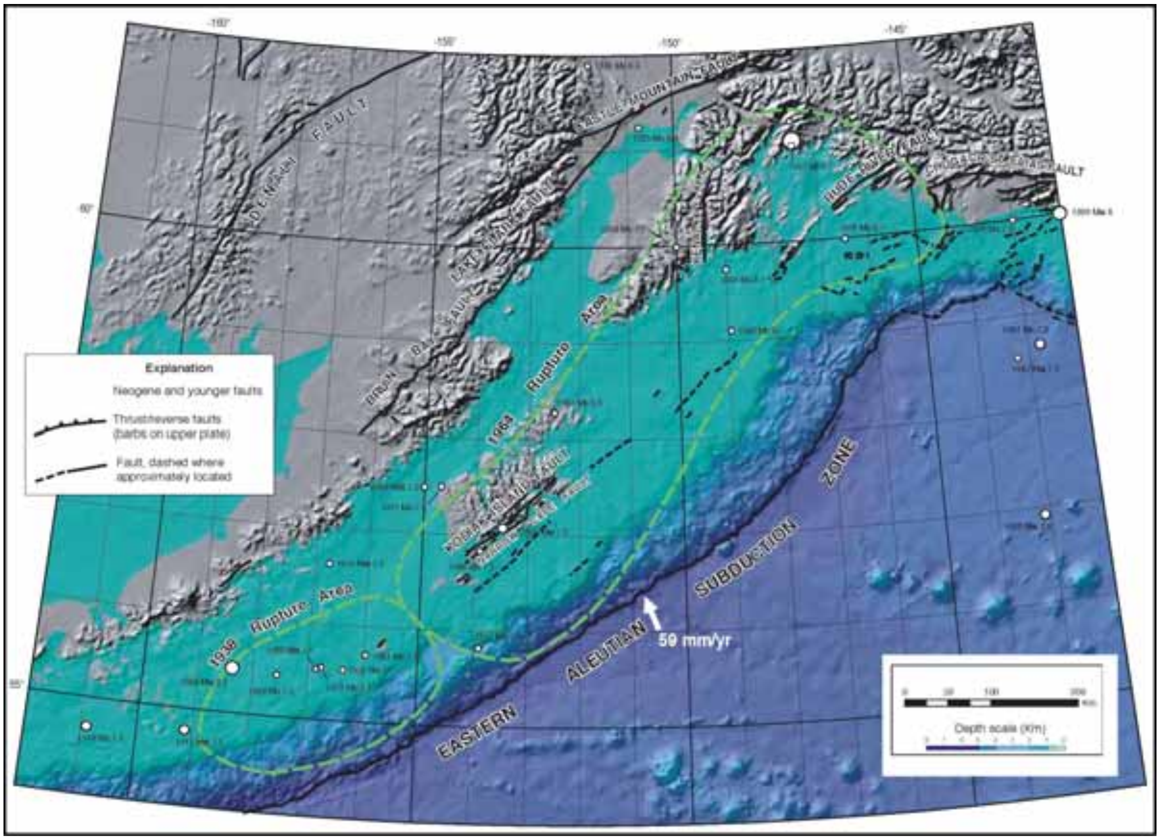

Figure 3-1. Tectonic Map of Region

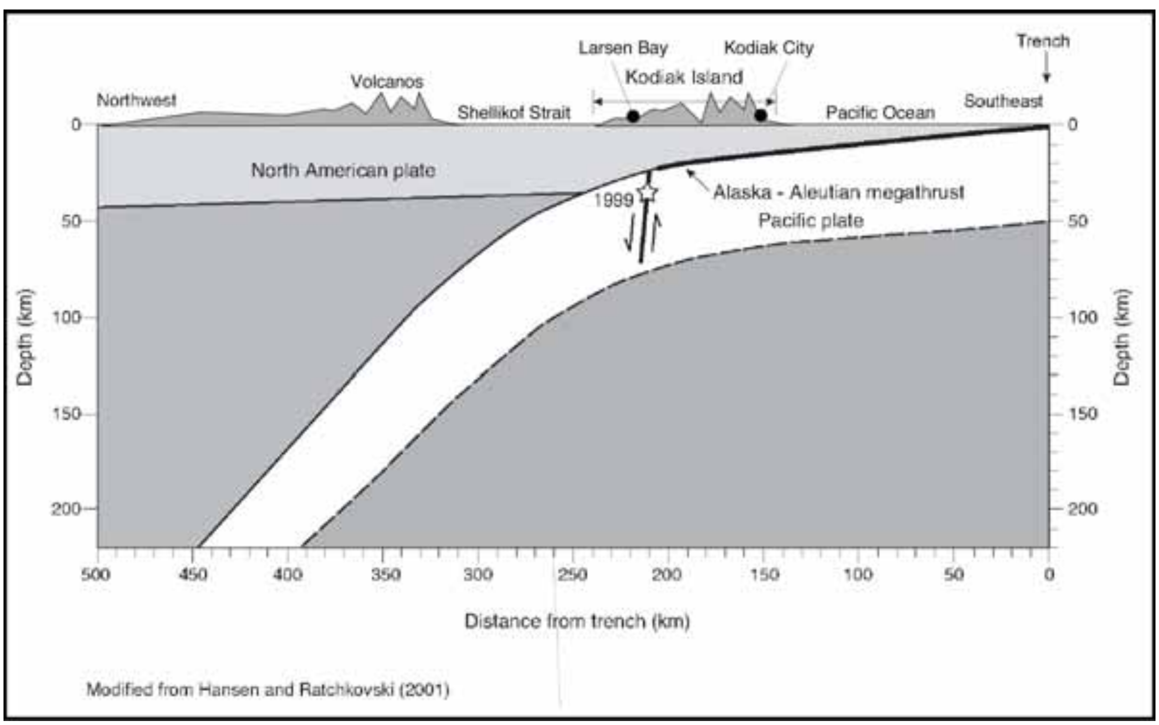

Figure 3-2. Cross Section Through Island (Land Mass Above 0 km Exaggerated)

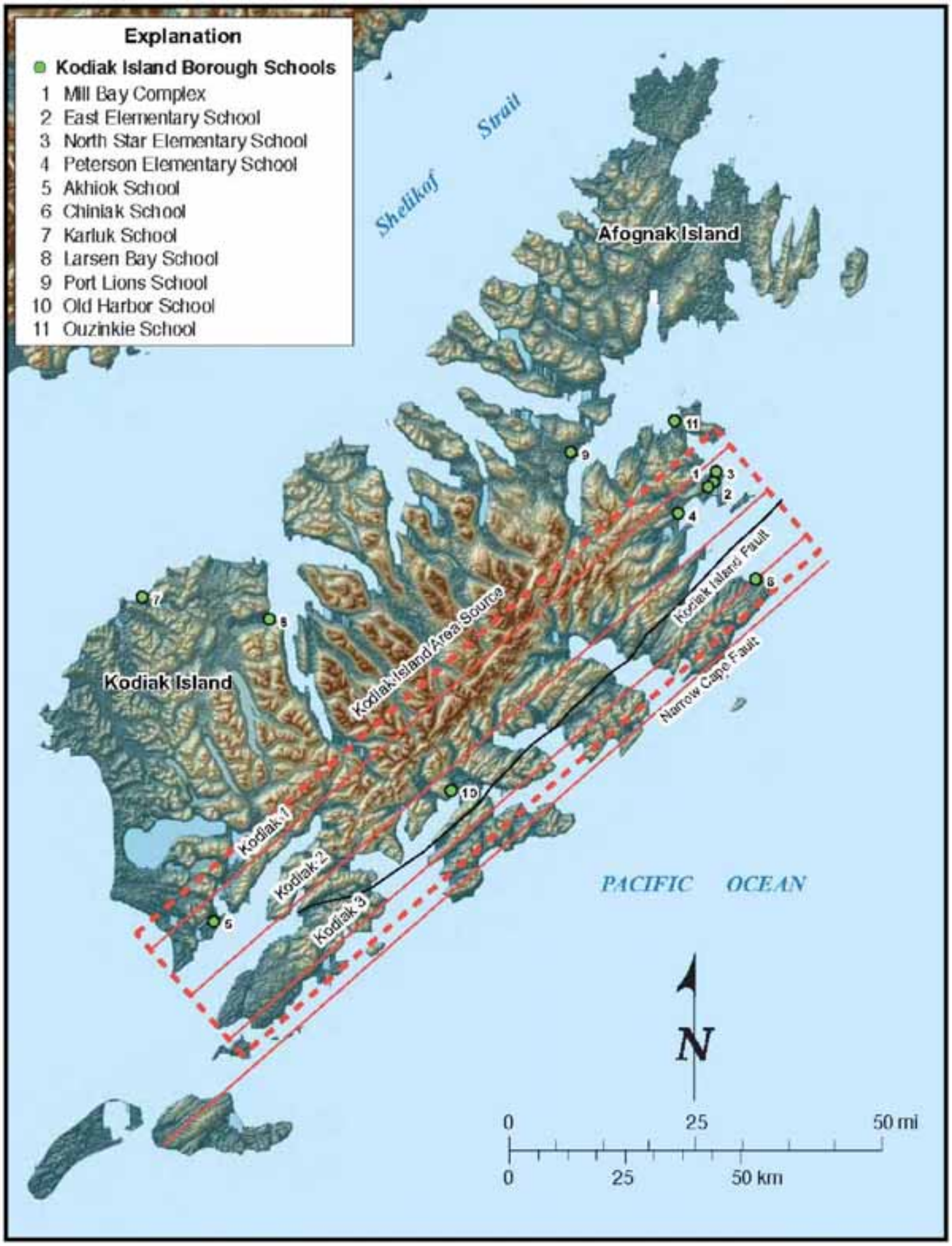

Figure 3-3. Crustal Faults on Kodiak Island

Table 3-1 shows the results from the ground shaking hazard analyses performed for each school site. As can be seen, the Chiniak school has the highest ground shaking hazard, owing to its close proximity to the active Narrow Cape fault. Schools on the northwest side of the island (Karluk, Larsen Bay, Port Lions, Ouzinkie) have the lowest ground shaking hazards.

Site Name	Peak Ground Acceleration (g)		
	475-year	975-year	2,475-year
Ahkiok School ROCK	0.47	0.62	0.81
Chiniak School ROCK	0.65	0.84	1.08
East Elementary ROCK	0.47	0.63	0.84
Karluk School ROCK	0.25	0.33	0.44
Larsen Bay School ROCK	0.25	0.33	0.44
Mill Bay Complex ROCK	0.47	0.63	0.84
North Star Elementary ROCK	0.47	0.65	0.89
Old Harbor School ROCK	0.52	0.68	0.88
Ouzinkie School ROCK	0.32	0.41	0.52
Peterson Elementary ROCK	0.47	0.63	0.84
Peterson Elementary SOIL	0.45	0.57	0.75
Port Lions School ROCK	0.28	0.35	0.45

Table 3-1. Ground Shaking Hazard at Each School Site

For design of new schools, the level of PGA (and corresponding response spectra) to be used should be no less than the 475-year values in Table 3-1. If the design following the 1997 UBC, then the 475-year motion should be used. If Kodiak City adopts the newer IBC 2000 code, then the design would be based on 2/3 of the 2,475 year motion, which is always somewhat higher than the 475-year motion.

3.2 Geotechnical Hazards

Each of the KIB schools was evaluated for potential for liquefaction, landslide, surface faulting, tsunami and differential settlement. The details of these evaluations are presented in (WLA 2006). Tables 3-2 and 3-3 summarize the findings.

School	Surface Faulting	Liquefaction	Tsunami	Landslide	Differential Settlement
Learning Center	VL	L	VL	VL	VL
High School	VL	L	VL	VL	VL
Middle School	VL	L	VL	VL	VL
Main Elementary	VL	L – M	VL	VL	L
East Elementary	VL	L	VL	VL	VL
Northstar Elementary	VL	VL	VL	VL	VL
Peterson Elementary	L	L	L	VL	VL

Table 3-2. Seismic and Geologic Hazard Assessment – Kodiak City Schools

School	Surface Faulting	Liquefaction	Tsunami	Landslide	Differential Settlement
Chiniak	VL	VL	VL	VL	VL
Old Harbor	VL	L	H	H	M
Akhiok	VL	L	L	VL	L
Karluk	VL	L	VL	VL	L
Larsen Bay	VL	VL	VL	VL	H
Port Lions	VL	VL	VL	VL	VL
Ouzinkie	VL	VL	VL	VL	VL

Table 3-3. Seismic and Geologic Hazard Assessment – Outlying Schools

A summary interpretation of Tables 3-2 and 3-3 follows, in context of building performance.

Surface Faulting

Very Low. Not likely to occur at the site and affect the building.

Low. The Peterson school site is situated very roughly along the projection of the Old Women's Mountain lineament. There is insufficient subsurface information to confirm that this lineament is a fault, and if it is a fault, whether it is active, and if it is active, whether it goes under or within a few tens of feet of the Peterson School. At the current time, the lack of confirmed evidence that there is a significant potential of surface faulting through the Peterson school building does not warrant adopting mitigation measures. However, should future work change the understanding of this fault, and it is shown that the fault is a) active (moved in the past 10,000 years or so); b) capable of moving more than several inches (ie., can produce magnitude 6.25 or higher earthquakes); and c) likely to have primary fault offset within 5 feet of the edges or underneath the building; then some mitigation measures might be suitable. The type of mitigation measures would depend upon the style of hazard, and could range from doing nothing (if the risk is very small), to isolating a portion of the building from normal occupancy, to abandoning parts or all of the building.

Liquefaction

Very Low. Not likely to occur at the site and affect the building, given a 475-year earthquake.

Low. Sites where seasonally saturated volcanic ash is present but does not underlie building foundations based on available drawings and means of construction. Differential settlement adjacent to the building is possible, on the order of 1 to 3 inches, given a 475 year earthquake; such settlement could damage buried pipes (if they are above the liquefiable layer), or cause minor damage to sidewalks and the like.

Low – Moderate. (Main Elementary) There is potential (unconfirmed) for volcanic ash buried below rock fill upon which parts of the slabs-on-grade may rest. The bulk of the building is supported on piles / piers beneath this layer. If the ash material was not removed, then there is potential for some settlement, and possible damage to utility pipes entering the building. Generally, this type of damage is not life-threatening, but can be relatively costly to repair.

Tsnumai

An extreme tsunami runup for these evaluations is defined as 1.5 times higher runup than was observed in the 1964 earthquake, or that based on numerical modeling.

Very Low. Extreme tsunami run-up from offshore landslides or earthquakes is not likely to affect the building, as the building elevation is more than 1.5 times higher than the maximum runup in 1964.

Low. An extreme tsunami could runup to within 5 feet below or just up to the ground floor elevation.

High. An extreme tsunami could runup to 2 feet or higher above the ground floor elevation of the Old Harbor gym building. (The classroom building would be Low.)

Landslide

Very Low. Not likely to occur at the site and affect the building.

High. This is assigned to the Old Harbor site. There is geologic evidence of debris flows down the hillside adjacent to the buildings (newer classroom building and older gym building). The debris flow hazard appears to have already been largely mitigated by the construction of a 2 to 5 meter high debris berm that separates the buildings from the hillside. It is recommended that the debris channel uphill of the berm be regularly monitored on a annual basis and after every large storm to assess the performance of the berm and whether debris flow deposits have filled the channel. If the channel fills with debris and begins to bury the berm, the material should be removed and the integrity of the berm maintained.

Differential Settlement

Very Low. Not likely to occur at the site and affect the building.

Low. The "low" designation addresses the potential for settlement at the site due to liquefaction.

Moderate. This is assigned to the Old Harbor site. There is ample evidence of ongoing differential settlement at the gym, manifested by the inability to completely move the gym-partition wall. Some of this damage may have been due to a series of M 6.5 to M 7 earthquakes in 1999 – 2000, which possibly produced PGA at the site on the order of 0.1g to 0.2g. Additional compaction / settlement is possible in the future, including strong ground shaking; but the settlement is not likely to exceed a few inches, so should not pose a material life safety threat given the style of construction of the buildings.

High. This is assigned to the Larsen Bay site. There is ample evidence of ongoing differential settlement at the gym, manifested by cracking in walls, and inability to move the gym-partition wall anymore. Some (possibly most or all) of this damage may have been due to a M 6.5 earthquake on July 11, 2000, which possibly produced PGA at the site on the order of 0.1g to 0.2g.

4.0 Seismic Retrofits

We evaluated each building for its likely performance for the 475-year and 2/3 of 2,475 year earthquakes, as well as earthquakes that produce ground shaking of PGA = 0.1g or PGA = 0.4g. Many of the building structures in the KIB system perform satisfactorily in the 475-year earthquake, but we found portions of five buildings that might perform poorly, or with substantial damage.

Further, we found that at every school building, there are a variety of mechanical and electrical equipment systems that have poor / no seismic restraint. We tabulated the equipment items in each building that should have anchorage / restraint added. For seismic retrofit, we recommend retrofits to building mechanical systems (furnaces, fuel oil, ventilation, water), library bookcases (over 4 feet tall), kitchen appliances (tall and prone to toppling causing egress and life safety issues), fire sprinkler heads through suspended ceilings (larger escutcheons), communication equipment and the like.

The following sections describe the recommended structural system retrofits.

4.1 Middle School

We examined a number of retrofit strategies for the Middle School. The primary upgrade concept is to provide shear walls along the outside perimeters of the building, to cure the non-ductile short column vulnerability (see Figure 4-1). The monitor level vulnerability will be solved by adding plywood atop the 3x6 sheathing, including the discontinuous step up section at the original attic (monitor level) windows. To the extent feasible, the upgrade will re-use existing materials. Over the interior corridor walls, additional plywood panels will be installed to provide continuity from the roof level diaphragm to the partial height hallway concrete walls. At most (not all) classrooms, the existing gypsum board partition wall will be replaced by a combination plywood wall, covered by gypsum board and wall finishes. In the two-story section of the building, selected exterior walls will be upgraded with additional shear walls.

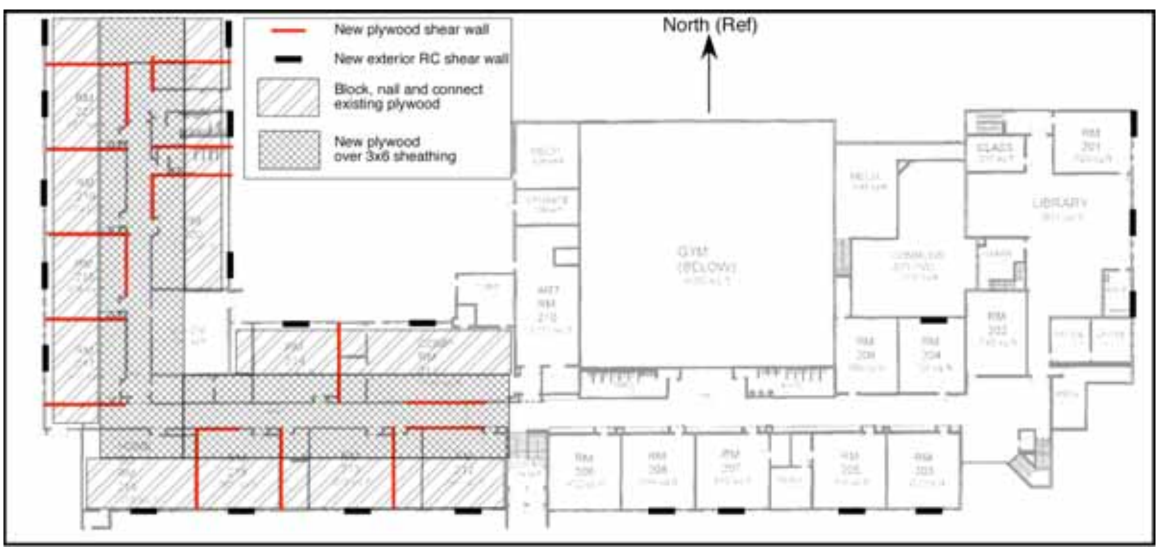

Figure 4-1. Middle School – Location of Seismic Upgrades

Based on discussion with the KIB staff, it was felt that adding the exterior shear walls to the outside of the building would not adversely impact the window visibility from the classrooms, so this was chosen as a least cost upgrade.

The upgrades will be designed using site specific ground motions of PGA = 0.47g (475 year motion), following the detailing requirements of the IBC 2000 code, using an importance factor I = 1.0. The completed structure will have good ductility.

Table 4-1 lists the costs. Base costs were developed using 2005 costs, and are escalated to mid-2007 for projected mid-point of construction.

Item	Cost
Install new reinforced concrete infill walls, dowelled into existing footings and columns, connected to new roof diaphragm, one per classroom, 14 total single story and 4 double story (1952, 1954 portions)	$49,750
Install 4 double story shear walls, 2 collectors, repair finishes, 1962 portion	$70,250
New plywood walls between each classroom. Remove finishes and gyp board. Nail new plywood. Attach to new roof diaphragm. Replace gyp board and wall finishes. 8 walls total	$117,600
Remove roofing material for 21,350 square feet. Block and nail existing plywood and add suitable edge connectors to new plywood and concrete walls. Install plywood over old 3x6 over all central corridors. Install new plywood walls from roof level to top of interior corridor concrete walls. Replace roofing.	$407,000
Repair finishes, outside of building, relocation costs	$50,000
Non-structural anchorage (2 water tank, 2 furnaces, 42 items total)	$10,966
Mobilization (10%) and contractors profit (15%)	$176,392
Escalation to 2007 (10.5%)	$103,483
Total construction	$985,441
Construction management by consultant (4%), construction management by KIB (3%), design cost (14%), KIB Project management (5%), Permits and Art (1%)	$266,069
Total	$1,251,510
Total per square foot (26,009 sq ft, 1952/1954 portions)	$48.11

Table 4-1. Seismic Upgrade of Middle School – 1952 Original, 1954, 1962 Classroom Additions

4.2 High School Library Wing

The existing high school library wing has reasonably good life-safety performance capability for earthquake loading up to about PGA = 0.25g or so. For ground motions much above PGA = 0.25g, the Core A and Core B walls may have substantial yielding; spandrel beams will have excessive plastic rotation and have permanent distortion; steel columns along line 18 may have permanent offsets. The building would have a significant chance of collapse for offshore earthquakes (M8+) that produce 60+ seconds of shaking with PGA much over 0.3g.

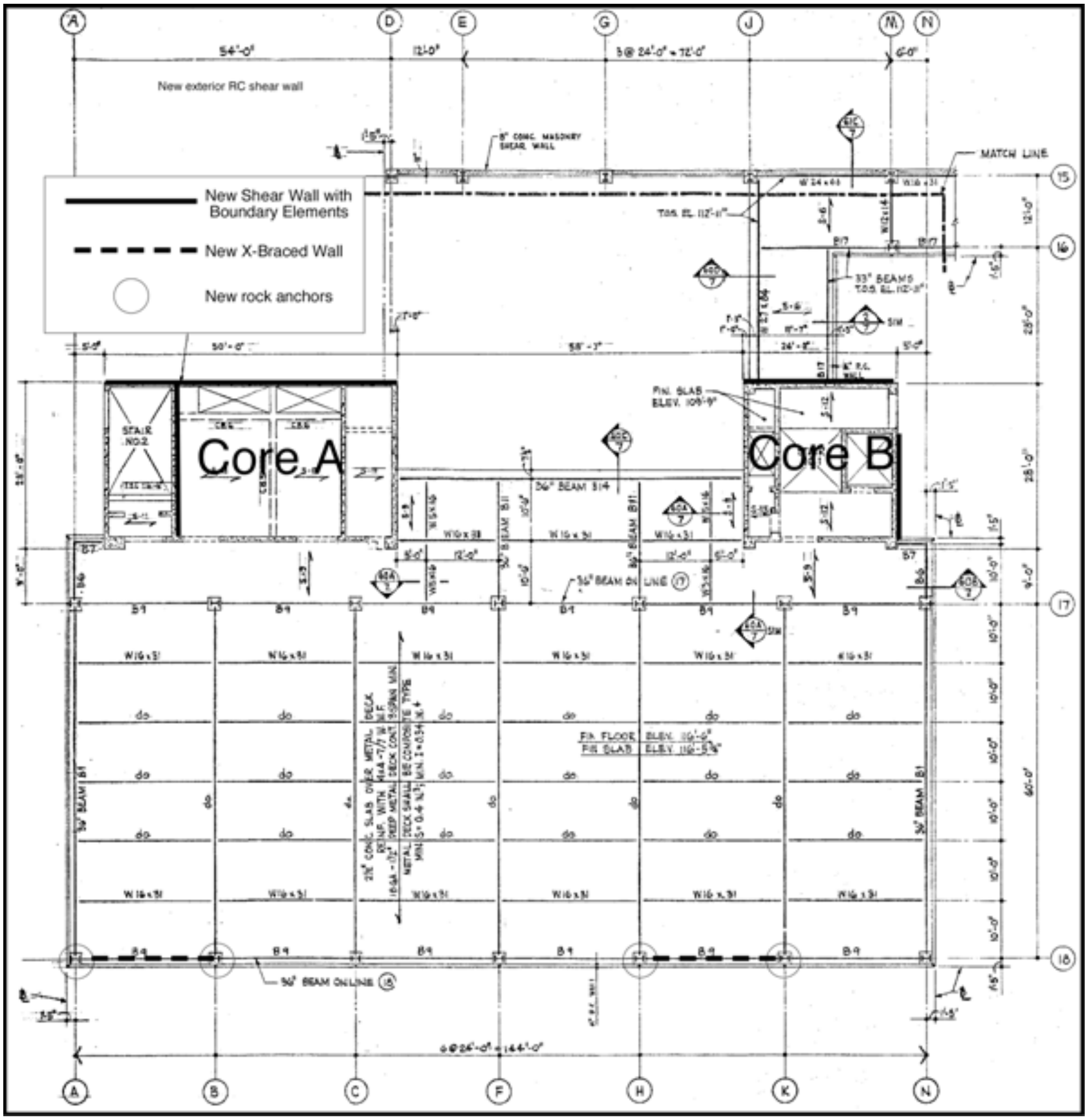

Figure 4-2. High School Library – Location of Seismic Upgrades

Given that the building might experience earthquake loading in its remaining design life on the order of PGA = 0.47g to 0.56g or so, upgrade is suggested for the building. The upgrade strategy is to add steel cross braces at two bays on line 18 (south façade, Figure 4-2) (preferred, keeps windows open, with some bracing visible; shear walls would close off windows). While these new braced walls will materially improve overall performance, the observed accumulated damage in Core A suggests that the walls of Cores A and B should be further reinforced to obtain a balanced design. Therefore, four additional bays (one each on the west and east facades adjacent to concrete floor diaphragms and two on the north face) will have reinforced concrete wall upgrades, in order to balance the stiffnesses of the structure and limit excessive torsion in the floor diaphragms. The foundations for the panel sections on line 18 will need modification to take net tension uplift loads. The upgraded building should be designed to resist about V=0.196 (working stress basis) or V=0.274 (load factor basis) in order to provide good life safety assurance (or better) for a code level (UBC 1997) earthquake with I = 1.0.

Item	Cost
Cross Bracing, South Wall, 2 Bays	$56,000
Tension Foundations, 4 locations	$31,000
Exterior reinforced concrete shear walls with boundary elements, foundations and dowelled into existing walls	$42,000
Interior reinforced concrete shear walls, new footings, remove and replace all finishes and re-route plumbing / electrical	$126,000
Mobilization (10%) and contractor's profit (15%)	$63,750
Escalation to 2006 (4.8%)	$15,300
Total construction	$334,050
Construction management by consultant (4%), construction management by KIB (3%), design cost (14%), KIB Project management (5%), Permits and Art (1%)	$90,200
Total	$424,250
Total per square foot (21,943 sq ft)	$19.33

Table 4-2. Seismic Upgrade of High School Library

4.3 Ouzinkie

The 1969 portion of the Ouzinkie School has serious seismic deficiencies. Essentially, the lateral load resisting capability is provided by the very limited bending moment capacity offered by the beam-to-post joints seen in Figure 2-16. Once the limited resistance offered by the dead weight of the building is overcome, the building will rack laterally. If it moves laterally more than about 3 to 4 inches, it will fall off its columns and drop several feet. At somewhat lesser lateral movements, mechanical systems that traverse through the 1969 section of the building, and continue to the 1979 or 1994 portions, will suffer damage.

The 1979 and 1994 additions to Ouzinkie appear to have reasonable seismic load paths, as confirmed by drawing review (1979 section) or as observed in the field (1994 section). While the plywood nailing details in the 1979 section are not clear on the drawings, and no destructive inspection was made, other details on the drawings that are clearly for seismic loading (heavy split ring connectors) strongly suggest that the remaining seismic load path was reasonably constructed.

For ground shaking in the east-west direction, the central 1969 section of the building will bump into the better-designed 1979 section (west side) or 1994 section (east side), and these will provide some measure of lateral stability. However, for ground shaking in the north-south direction, the adjacent better-built sections will provide no resistance, and the central section can readily fail.

Figure 4-3 shows the layout of the new foundations and seismic bracing under the central portion. The cross bracing would be similar to that seen in Figure 4-4 that is used on the southern side of the building. The new foundations and bracing would be sufficient to address the uncertain nailing system in the floor diaphragm by creating a series of short sub-diaphragms. On the northern side of the building, the double height of the facility coupled with the taller distances between the floor and foundation suggest the installation of grade beam footings along the perimeter and installation of plywood shear walls on all four sides. In final design, the selection of steel rod cross bracing or plywood walls could be modified to reflect the simplest installation method as well as access issues.

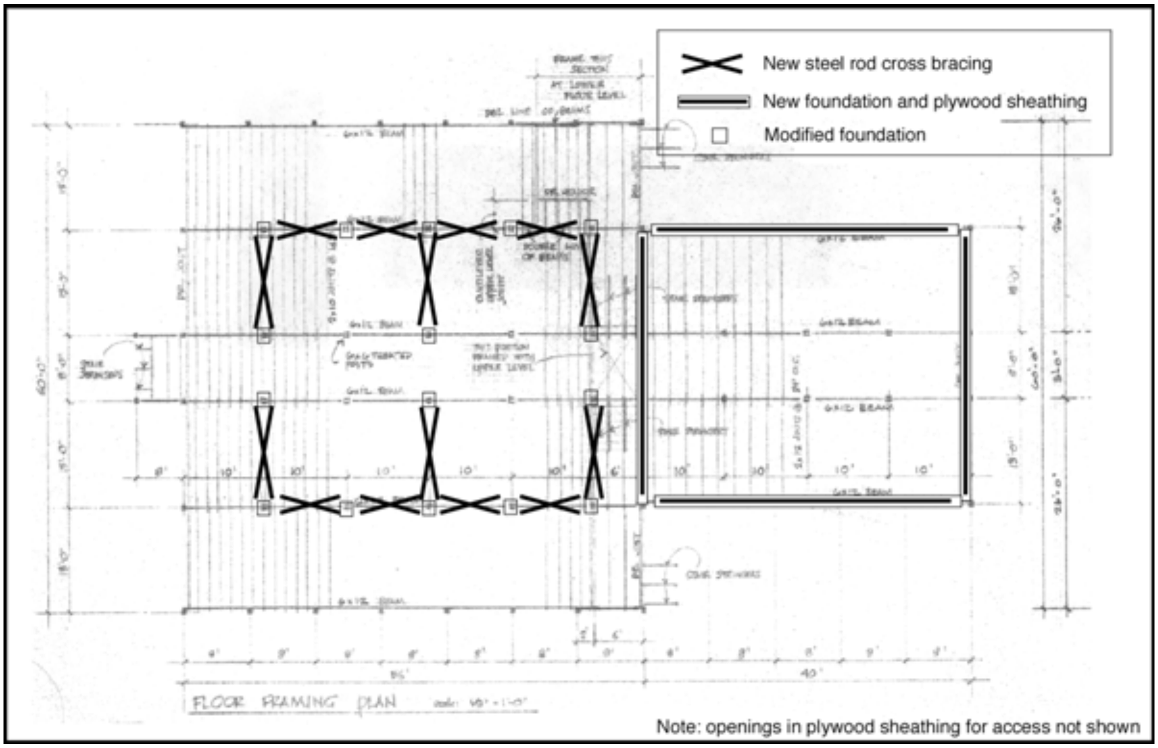

Figure 4-3. Seismic Upgrade, Central Portion, Ouzinkie

Figure 4-4. Addition of New Steel Cross Braces

During the site visit, visual inspection under the 1979 portion of the building showed no evidence of cross bracing. At the time of the site visit, no drawings for that portion of the building were available. Since that time, drawings were located showing that at some locations, there should be 3x6 wood cross braces. It is recommended that KIB confirm that these braces were in fact installed; if not, upgrades of the type in Figure 4-3 will also be required under the 1979 portions of the building.

Table 4-3 lists the costs for seismic upgrade of Ouzinkie, including the 1969 structure, the emergency generator structure and all anchorage essential non-structural equipment items. The somewhat higher design and construction management fees reflects the smaller level of effort, plus allowance for extra time to get to this site (requires plane or boat to get access from Kodiak City).

Item	Cost
Site work, prepare for foundations (hand dig)	$8,000
Reinforced concrete footings (2 feet deep, 1 foot wide)	$14,000
Install plywood and cross bracing	$16,000
Bolted connections (32)	$32,000
Generator building concrete foundation, bolt walls	$8,000
Non-structural anchors (generator, brace ceiling mounted fan, 16 desktop monitors, 2 water tanks, 1 furnace, 1 glycol tank	$7,500
Mobilization (10%) and contractor's profit (15%)	$21,375
Escalation to 2006 (4.8%)	$5,125
Total construction	112,000
Construction management by consultant (6%), construction management by KIB (5%), design cost (16%), KIB Project management (5%), Permits and Art (1%)	$37,000
Total	$149,000
Total per square foot (5,040 sq ft)	$29.56

Table 4-3. Seismic Upgrade of Ouzinkie

4.4 Peterson

The 1946 portion of the Peterson school (64.5 feet x 155 feet in plan) was upgraded in 1986 by replacing about half of the outside windows with concrete masonry walls. However, these walls were installed only up to the top of the windows, and the original glass block walls still remain under the stucco exterior. Thus, the building remains somewhat vulnerable for ground shaking in the north-south direction. In the east-west direction, the existing wind-braces are now loaded with the extra weight of the exterior walls, to the extent that they might snap at PGA~0.1g, after which the exterior steel columns (5I10) and new concrete masonry walls will provide some limited additional capacity.

The recommended upgrades are to replace the interior classroom division walls (8 total) with new plywood shear walls; install new concrete footings under the plywood walls to take the overturning loads; remove portions of the built-up roofing and then upgrade the nailing of the existing plywood to the new plywood shear walls; remove the exterior glass block walls above the masonry infill walls and replace with concrete wall with suitable attachment to the masonry units below and the roof system above. These upgrades would be done assuming $V = 0.47g * 2.5 / 6 = 0.196W$, where W is the current weight of the building, including provision for likely snow loads.

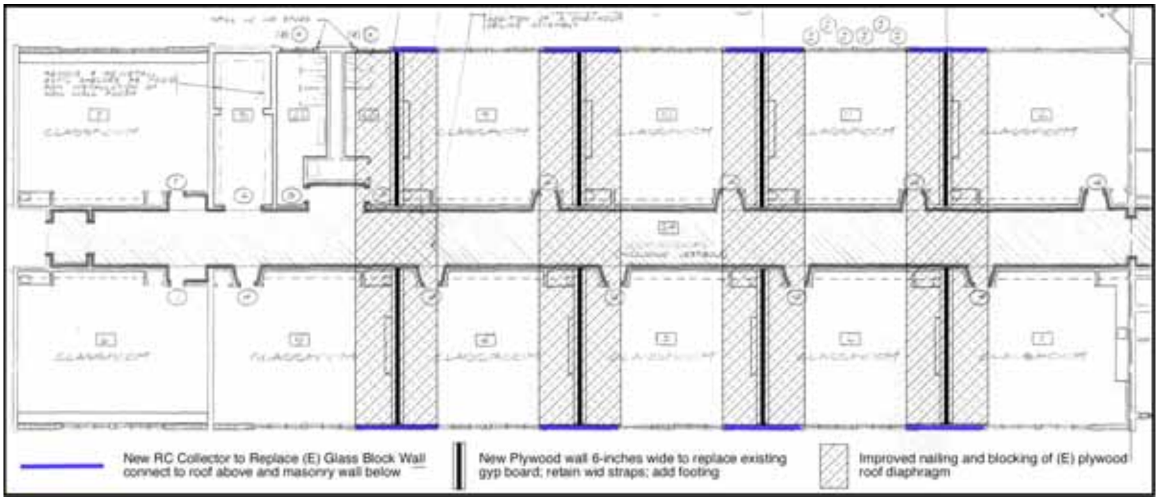

Figure 4-4. Seismic Upgrade of Peterson (1946 Section)

Item	Cost
Demolish top portions of north-south walls (glass block walls)	$67,000
Install collectors, north south (reinforced concrete, connect to masonry below and roof above)	$33,300
Install foundations for new plywood shear walls (8 locations)	$20,000
Demolish classroom divider walls, install new plywood wall (retain air space for sound-proofing, insulation and wind strap)	$80,000
Nail roof, add blocking as required, replace built up roof	$30,000
Replace all finishes (interior gyp board, exterior stucco, paint to match	$40,000
Non-structural anchors (allowance)	$10,000
Mobilization (10%) and contractor's profit (15%)	$70,200
Escalation to 2006 (4.8%)	16,800
Total construction	367,300
Construction management by consultant (6%), construction management by KIB (5%), design cost (16%), KIB Project management (5%), Permits and Art (1%)	$121,200
Total	$488,500
Total per square foot (5,040 sq ft)	$48.86

Table 4-4. Seismic Upgrade of Peterson

4.5 High School Gym

Section 2.5 outlines the possible reasons for the damaged masonry walls within the High School Gym.

In addition to these cracked walls, the non-structural masonry shows evidence of pulling away from the steel columns in the gym at a number of locations.

Given these issues, is would appear that the cracked walls (Figure 2-24), as well as the other cracked masonry walls, while unsightly, do not present a major life safety threat for toppling, as long as: a) the roof to wall connections, even if loose, do not completely break away; b) the walls, even damaged, can be shown to remain integral (standing) at PGA = 0.47g, accommodating the building drifts as the lateral force resisting system braced frames yield.

Two upgrade alternatives were considered.

- Alternative 1. The building can be upgraded with a heavier and stiffer roof diaphragm (reinforced concrete deck) that would connect the exterior walls with the masonry walls; coupled with upgraded foundations and shotcrete walls. To balance the overall design, new reinforced concrete shear walls and foundations would be required on lines 3 and 15, between column lines P and T. To balance the design for torsion, another full height reinforced concrete wall (with foundation) would be placed at the far west edge of the building. This upgrade would be done to provide good life safety assurance at PGA = 0.47g. The increased stiffness of the building would limit damage at lower PGA levels. the upgrade scheme and costs are in Figure 4-5 and Table 4-5.
- Alternative 2. The existing walls can be repaired (epoxy injection or with a thin concrete shotcrete wall attached), and the connections of the walls can be modified to essentially unhook them from the exterior braced walls and the roof diaphragm. In this way, the building will perform as originally intended, with reasonable life safety assurance for PGA = 0.40g. The cost to perform this work is $40,000. This would somewhat reduce damage at moderate levels of ground shaking and slightly improve the performance of the building at high levels of shaking, owing to the reduced damage to the roof diaphragm at the masonry walls.

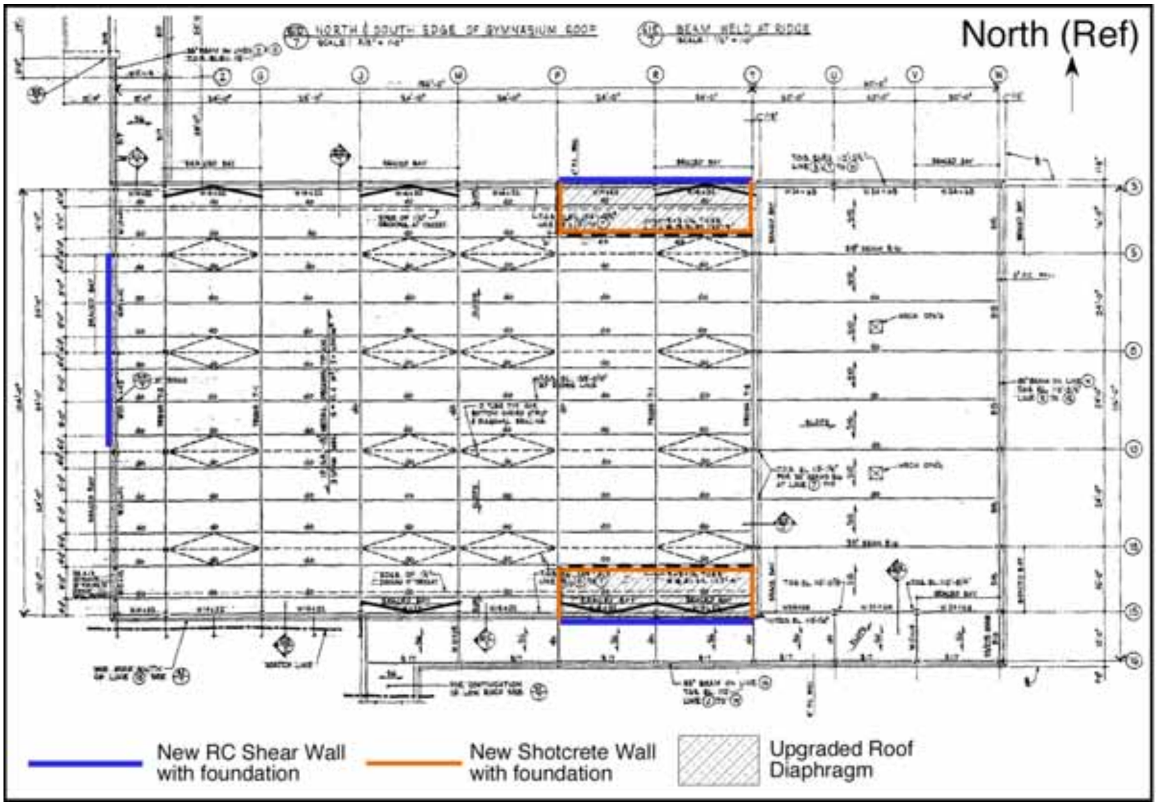

Figure 4-5. Seismic Upgrade of High School Gym for PGA = 0.47g

Item	Cost
Remove finishes	$8,000
Install foundations	$60,000
Install shear walls and shotcrete walls	$199,500
Modify roof diaphragm	$16,000
Replace all finishes, paint	$20,000
Mobilization (10%) and contractor's profit (15%)	$58,900
Escalation to 2006 (4.8%)	14,100
Total construction	308,500
Construction management by consultant (6%), construction management by KIB (5%), design cost (16%), KIB Project management (5%), Permits and Art (1%)	$101,800
Total	$410,300
Total per square foot (18,720 sq ft)	$21.92

Table 4-5. Costs for Seismic Upgrade of Gym for PGA = 0.47g

5.0 Fragility and Damage States

Benefit Cost Analyses for purposes of the PDM-C 2006 have been performed for selected buildings to be considered for seismic upgrade. These buildings are:

- Middle School 1952 and 1954 Portions
- High School Library Wing
- Ouzinkie Original
- Peterson 1946 Section
- High School Gym Walls

The prediction of damage for the buildings is done using fragility curves. For each building, a fragility curve is presented for each of four damage states:

- Collapse
- Extensive
- Moderate
- Slight

These damage states are descriptive. From the descriptions of the damage states provided in this section, the user can understand the nature and extent of the physical damage to a building type from the damage prediction output. From these descriptions, life-safety, societal and monetary losses which result from the damage can be estimated. Building damage can best be described in terms of the nature and extent of damage exhibited by its components (beams, columns, walls, ceilings, piping, HVAC equipment, etc.). For example, such component damage descriptions as "shear walls are cracked", "ceiling tiles fell", "wall panels fell out", etc., used together with such terms as "some" and "most" would be sufficient to describe the nature and extent of overall building damage.

Damage to nonstructural components of buildings (i.e., architectural components, such as partition walls and ceilings, and building mechanical/electrical systems) primarily affect monetary and societal losses while damage to structural components (i.e., the gravity and lateral load resisting systems) of buildings affect the expected casualty estimates, as well as other losses. For this project, we have provided fragility curves for damage to the structural components, and separately for the nonstructural components.

Another characteristic of building damage is that it varies from "none" to "complete" as a continuous function of building deformations (building response). Wall cracks may vary from invisible or hairline cracks to cracks of several inches width. Furthermore, damage of different nature or form may occur at different building deformations. As it is impractical to linguistically describe building damage as a continuous function, it is necessary to develop general descriptions for ranges of damage.

This methodology describes extent and severity of damage to structural components of a building separately by one of four ranges of damage or damage states: slight, moderate, extensive, and complete. General descriptions of these damage states are provided for the two central offices with reference to observable damage incurred. Damage predictions resulting from this physical damage estimation method are then expressed in terms of the probability of a building being in any of these four damage states.

In addition to the five structural upgrades, a variety of non-structural upgrades are needed at every school building. The non-structural upgrades are geared to anchor or restrain essential equipment (furnaces, water tanks, ventilation); anchor / restrain tall library bookshelves; provide suitable flexibility to water pipes that cross between building isolation joints; anchor/restrain tall and heavy counter top kitchen equipment; provide increased space for fire sprinkler heads through suspended ceilings; etc.

The following sections describe the damage states and fragilities for the buildings in their as-is and seismically upgraded conditions. Section 6 describes the benefit cost analyses done for each building.

5.1 Middle School

Slight Structural Damage: Flexural or shear type hairline cracks in some columns near joints or within joints. Small plaster or gypsum-board cracks at corners of door and window openings and wall-ceiling intersections. Small cracks are assumed to be visible cracks with a maximum width of less than 1/8", while cracks wider than 1/8" are referred to as "large" cracks.

Moderate Structural Damage: Most exterior columns exhibit hairline cracks. Large plaster or gypsum-board cracks at corners of door and window openings; small diagonal cracks across shear wall panels exhibited by small cracks in gypsum wall panels.

Extensive Structural Damage: Some of the exterior columns have reached their ultimate capacity indicated spalled concrete and buckled main reinforcement; some columns may have suffered shear failures or bond failures at reinforcement splices which may result in partial collapse. Large diagonal cracks across gypsum board wall panels; permanent lateral movement of floors and roof; cracks in foundations; splitting of wood sill plates and/or slippage of structure over foundations; severe distortion of 3x6 roof sheathing and pull away from walls; small foundations cracks.

Complete Structural Damage: Structure is collapsed or in imminent danger of collapse due to brittle failure of non-ductile column elements or loss of frame stability.

Structure	Slight		Moderate		Extensive		Collapse	
Case	A	Beta	A	Beta	A	Beta	A	Beta
1. As Is	0.12	0.64	0.15	0.64	0.27	0.64	0.45	0.64
2. Upgraded	0.18	0.50	0.30	0.50	0.90	0.50	1.60	0.50

Table 5-1. Fragilities – Middle School – 1952 Original, 1959, 1962 Classroom Additions

5.2 High School Library Wing

The fragility of the existing and proposed upgraded High School Library Wing is listed in Table 5-2. Prior earthquakes at the site (est. PGA about 0.10g to 0.15g) have already damaged the Core concrete towers.

Slight Structural Damage: Minor deformations in connections or hairline cracks in few welds. Torsional impact on the Core A section results in hairline cracks in the Core A concrete structure.

Moderate Structural Damage: Some steel members have yielded exhibiting observable permanent rotations at connections; few welded connections may exhibit major cracks through welds or few bolted connections may exhibit broken bolts or enlarged bolt holes. Torsional impact on the Core A section results in opening cracks in the Core A concrete structure to about 1/16 inch. It is estimated that prior earthquakes at this site have already resulted in this level of damage.

Extensive Structural Damage: The strong beam / weak column design results in gross yielding in the columns leading to significant lateral deformations of the structure. Some of the structural members or connections may have exceeded their ultimate capacity exhibited by major permanent member rotations at connections, buckled flanges and failed connections. A few cracked welds. Partial collapse of portions of structure would possibly be due to failed critical elements and/or connections. Substantial yielding in Core A concrete tower. Most concrete shear walls in the Core towers have exceeded their yield capacities; some walls have exceeded their ultimate capacities indicated by large, through-the wall diagonal cracks, extensive spalling around the cracks and visibly buckled wall reinforcement. Damage to the Core Towers results in all loads being resisted by the steel frames.

Complete Structural Damage: Significant portions of the structural elements have exceeded their ultimate capacities or some critical structural elements or connections have failed resulting in dangerous permanent lateral displacement, partial collapse or collapse of the building. The Core Towers have suffered general yielding of reinforcement, wide x-cracks form with loss of strength.

Structure	Slight		Moderate		Extensive		Collapse	
Case	A	Beta	A	Beta	A	Beta	A	Beta
1. As Is	0.15	0.64	0.20	0.64	0.39	0.64	0.77	0.64
2. Upgraded	0.33	0.50	0.63	0.50	1.26	0.50	2.17	0.50

Table 5-2. Fragilities –High School Library Wing

5.3 Ouzinkie

The following describes the damage states for the 1969 (original) portion of the building.

Slight Structural Damage: Small plaster or gypsum-board cracks at corners of door and window openings and wall-ceiling intersections. Small cracks are assumed to be visible cracks with a maximum width of less than 1/8"; cracks wider than 1/8" are referred to as "large" cracks.

Moderate Structural Damage: Large plaster or gypsum-board cracks at corners of door and window openings; small diagonal cracks across shear wall panels exhibited by small cracks in gypsum wall panels.

Extensive Structural Damage: Large diagonal cracks across gypsum board wall panels; permanent lateral movement of floors and roof; some shifting of 6x6 posts; damage to commodities that are rigidly braced and traverse the 1979, 1969 and 1994 interfaces of the building.

Complete Structural Damage: Structure is collapsed or in imminent danger of collapse due to rotation of 6x6 posts, failure of post-to-beam connections or loss of frame stability.

Structure	Slight		Moderate		Extensive		Collapse	
Case	A	Beta	A	Beta	A	Beta	A	Beta
1. As Is	0.12	0.64	0.19	0.64	0.37	0.64	0.60	0.64
2. Upgraded	0.26	0.50	0.55	0.50	1.28	0.50	2.01	0.50

Table 5-4. Fragilities – Ouzinkie – 1969 Portion of Building

5.4 Peterson

The following describes the damage states for the 1946 (original) portion of the building.

Slight Structural Damage: Small plaster or gypsum-board cracks at corners of door and window openings and wall-ceiling intersections. Small cracks are assumed to be visible cracks with a maximum width of less than 1/8"; cracks wider than 1/8" are referred to as "large" cracks.

Moderate Structural Damage: Wind-strap metal straps yielded or snapped. Large plaster or gypsum-board cracks at corners of door and window openings; small diagonal cracks across classroom shear wall panels exhibited by small cracks in gypsum wall panels. Minor cracks in exterior plaster.

Extensive Structural Damage: Large diagonal cracks across gypsum board wall panels; permanent lateral movement of floors and roof; some shifting of 6x6 posts supporting interior roof at corridors; damage to commodities that are rigidly braced and traverse the 1956 to 1946 interfaces of the building; major yielding of exterior steel columns and masonry walls; distortion of glazing system with some glass breakage.

Complete Structural Damage: Structure is collapsed or in imminent danger of collapse due to rotation of 6x6 posts, failure of post-to-beam connections, failure of wind straps, fall out of glass block wall elements or loss of frame stability.

Structure	Slight		Moderate		Extensive		Collapse	
Case	A	Beta	A	Beta	A	Beta	A	Beta
1. As Is	0.10	0.64	0.15	0.64	0.25	0.64	0.50	0.64
2. Upgraded	0.31	0.50	0.66	0.50	1.35	0.50	2.44	0.50

Table 5-4. Fragilities – Peterson – 1946 Portion of Building

5.5 High School Gym

The following describes the damage states for the High School Gym for the as-is and retrofitted to PGA = 0.47g condition.

Slight Structural Damage: As Is: few steel braces have yielded which may be indicated by minor stretching and/or buckling of slender brace members; minor cracks in welded connections; small cracks in non-structural reinforced masonry walls. Retrofitted: Diagonal hairline cracks on most concrete shear wall surfaces; minor concrete spalling at few locations.

Moderate Structural Damage: As Is: Some steel braces have yielded exhibiting observable stretching and/or buckling of braces; few braces, other members or connections have indications of reaching their ultimate capacity exhibited by buckled braces or cracked welds. Large cracks in non-structural reinforced masonry walls; damage to roof diaphragm connections where connected to non-structural walls.

Retrofitted: Most shear wall surfaces exhibit diagonal cracks; some shear walls have exceeded yield capacity indicated by larger diagonal cracks and concrete spalling at wall ends; a few steel braces have yielded,

Extensive Structural Damage: As Is: most steel braces and other members have exceeded their yield capacity resulting in significant permanent lateral deformation of the structure. Some structural members or connections have exceeded their ultimate capacity exhibited by buckled or broken braces, flange buckling, broken welds. Anchor bolts at columns may be stretched. Partial collapse of portions of structure is possible due to failure of critical elements or connections, with life safety risk to passersby. Non-structural walls seriously cracked and visibly out of alignment. Retrofitted: Most concrete shear walls have exceeded their yield capacities; some walls have exceeded their ultimate capacities indicated by large, through-the wall diagonal cracks, extensive spalling around the cracks and visibly buckled wall reinforcement; Some steel braces have yielded exhibiting observable stretching and/or buckling of braces

Complete Structural Damage: As is: Most the structural elements have reached their ultimate capacities or some critical members or connections have failed resulting in dangerous permanent lateral deflection and partial collapse or collapse of the building. Non-structural walls may topple locally. Retrofitted: Structure has collapsed or is in imminent danger of collapse due to failure of most of the shear walls and failure of some critical beams or columns. Most steel braces and other members have exceeded their yield capacity.

Structure	Slight		Moderate		Extensive		Collapse	
Case	A	Beta	A	Beta	A	Beta	A	Beta
1. As Is	0.15	0.64	0.35	0.64	0.74	0.64	1.43	0.64
2. Upgraded	0.28	0.50	0.53	0.50	1.06	0.50	1.82	0.50

Table 5-4. Fragilities – High School Gym – Upgraded to PGA = 0.47g

Table 5-5 examines the option of just repairing the non-structural walls by essentially decoupling them from the main structural lateral force braced frame resisting system. As there would be essentially no modification to the existing building system, there is no reduction in uncertainty as to the quality of construction or materials used. At the extensive damage state, there is a credible chance (as is) that the masonry walls would partially collapse, being a falling hazard to passerby.

Structure	Slight		Moderate		Extensive		Collapse	
Case	A	Beta	A	Beta	A	Beta	A	Beta
1. As Is	0.15	0.64	0.35	0.64	0.74	0.64	1.43	0.64
2. Upgraded	0.24	0.64	0.41	0.64	0.76	0.64	1.46	0.64

Table 5-5. Fragilities – High School Gym – Walls Repaired

5.6 Scenario Analyses

Each building in the KIB was evaluated as to how it might perform in four different scenario earthquakes. By "scenario" earthquake, it is meant that an earthquake that produces a specific PGA at the site has occurred. The four scenario earthquakes are:

- PGA = 0.1g. This is representative of small local or larger distant earthquakes that might affect the school. Most of KIB's schools have already experienced earthquakes with this approximate level of shaking.
- PGA = 0.4g. This is representative of a large nearby earthquake. Up until the mid-1990s, this is what was meant as being in "seismic zone 4" per the UBC.
- PGA = 475 years. Using modern seismic hazard analyses, the 475-year earthquake PGA represents the best estimate of an earthquake that has 10% chance of occurring in the next 50 years. The UBC (1994 edition) and many other codes base seismic design on this concept.
- PGA = 2/3 of 2,475 years. Using modern seismic hazard analyses, the 2,475-year earthquake PGA represents the best estimate of an earthquake that has 2% chance of occurring in the next 50 years. The IBC (2000 and 2003 editions) code bases seismic design on this concept.

Figures 5-1 through 5-4 summarize the results for each building. The results are presented for each building for each of four levels of earthquake, for four possible damage states:

- Slight
- Moderate
- Extensive
- Complete

Sections 5.1 through 5.5 describe what is meant by each damage state for the buildings with the greatest chance of significant damage in large earthquakes. For example, Figure 5-4 shows that the High School Library wing has about a 25% chance of being in the complete damage state, given an earthquake that produces PGA = 0.56g at that site. For that same level of earthquake, the nearby Vocational Wing has a 2% chance of being in the complete damage state.

When interpreting the results in Figures 5-1 to 5-4, the following factors should be kept in mind:

- For Figures 5-3 and 5-4, the actual PGA values are based on the data in Table 3-1. The listed PGA value are specific for the Mill Bay Complex.
- These analyses are based on a number of assumptions and address uncertainties and randomness. By randomness, it is meant that although a scenario earthquake might most likely produce PGA = 0.56g at a site, there is considerable variation in ground motions in a given earthquake over short distances, generally on the order

of ±50%. This accounts for about half the total variation in predicting the actual damage state of the building. By uncertainty, it is meant that the strength of construction materials is generally unknown (some steel might be specific as having a minimum strength, and actually have just that strength, while another heat of steel might have 50% more strength); there is uncertainty as to the quality of construction; there is uncertainty as to the actual weight of the building at the time of the earthquake, etc.

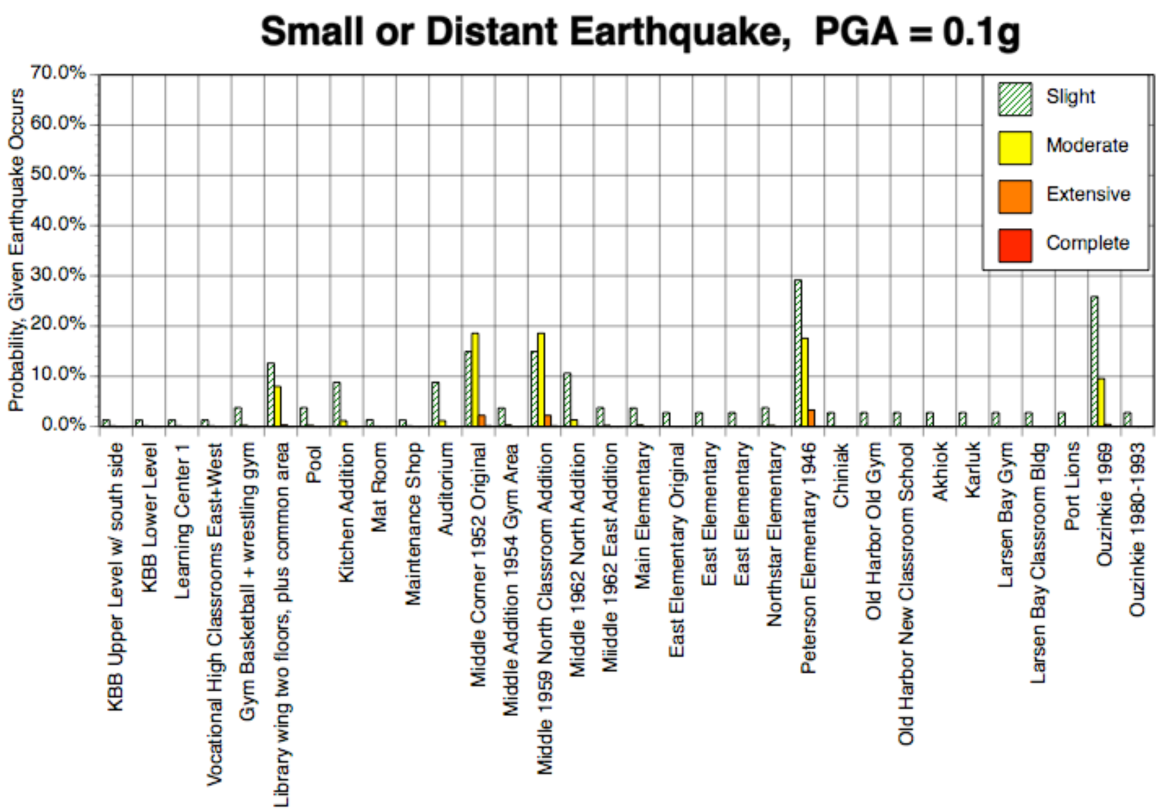

Figure 5-1. Building Performance: PGA = 0.1g Scenario Earthquake

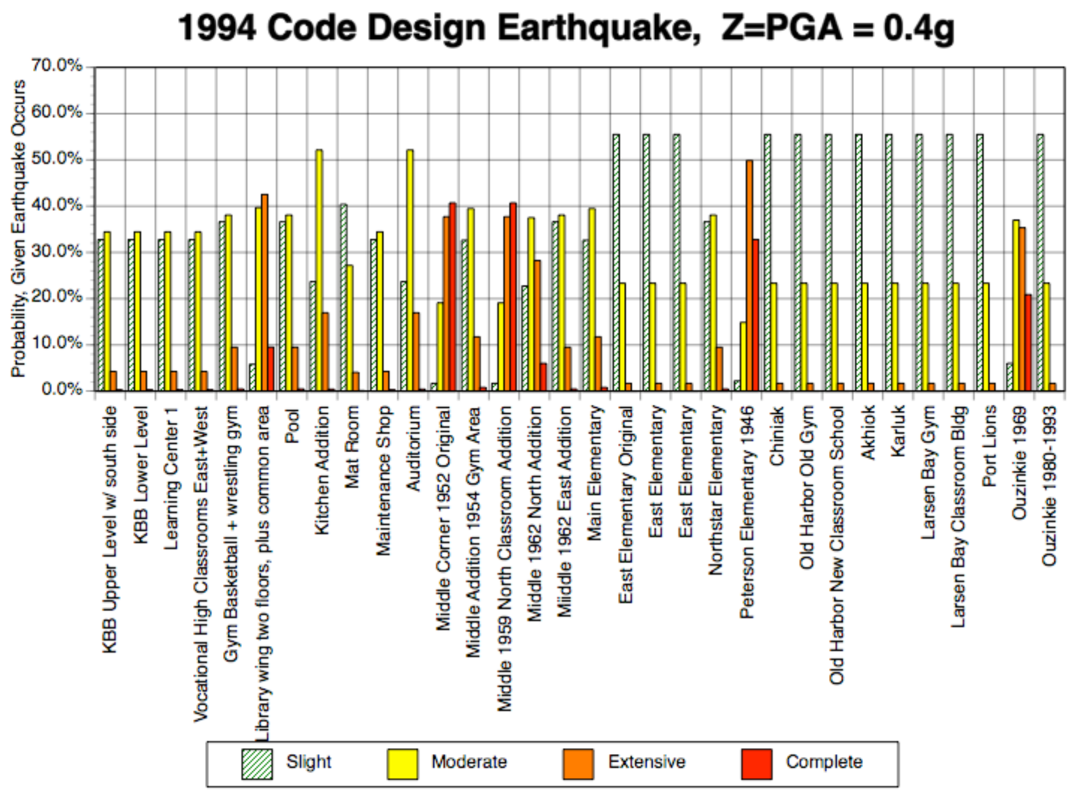

Figure 5-2. Building Performance: PGA = 0.4g Scenario Earthquake

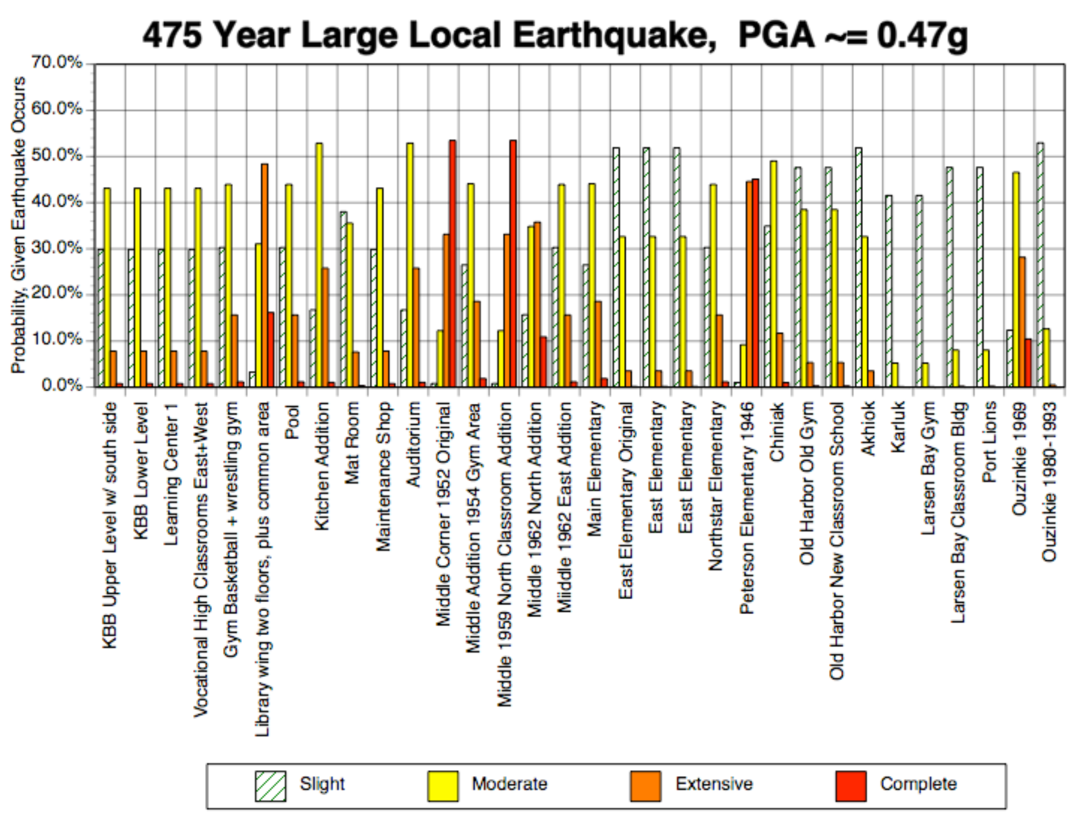

Figure 5-3. Building Performance: 475 Year Scenario Earthquake

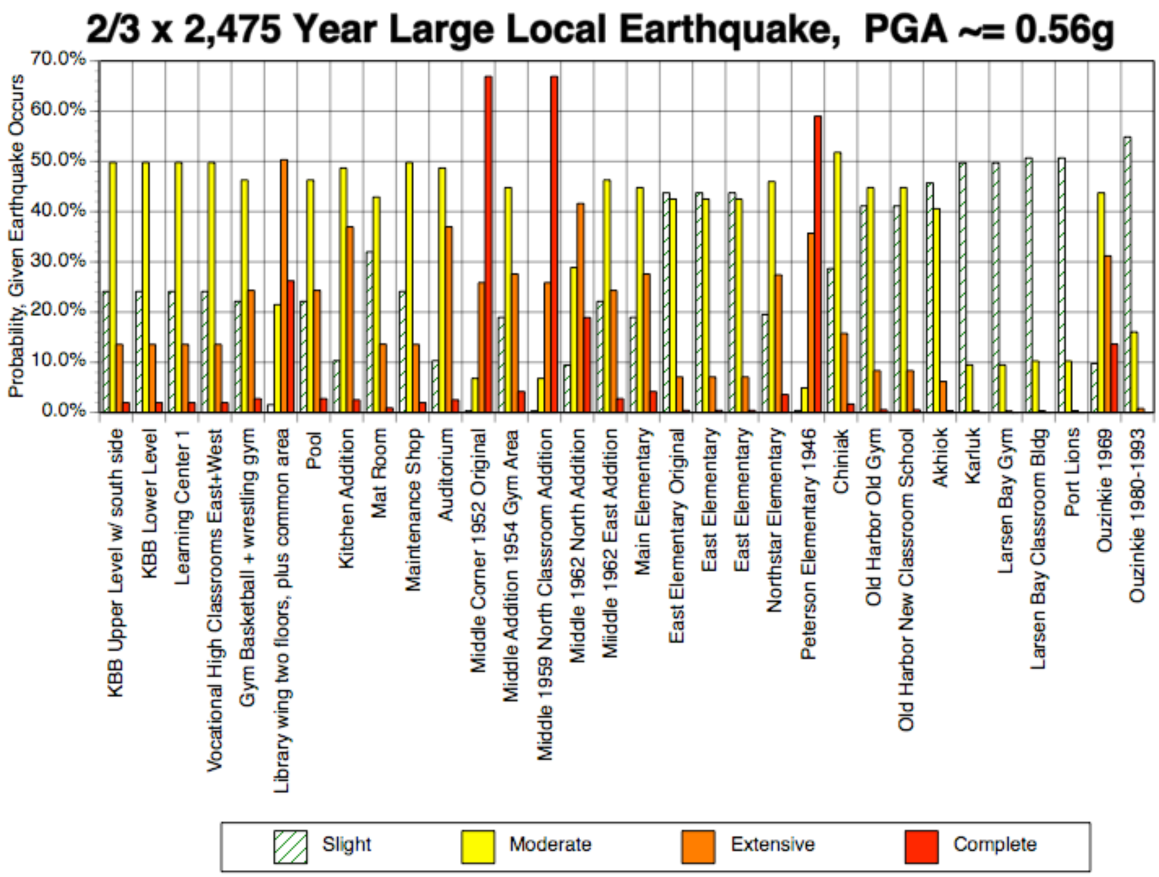

Figure 5-4. Building Performance: 2/3 of 2.475 Year Scenario Earthquake

6.0 Benefit Cost Analyses

Based on the structural engineering evaluations and cost estimates in this report, benefit cost analyses were performed to examine the cost effectiveness of the proposed seismic mitigation projects.

The analyses were performed using the analytical tools and models required by FEMA (FEMA Benefit Cost Toolkit 2.0, January 2005). A description of these models and results for the upgrade of the Middle School are provided in Goettel (2006).

Analyses were performed for each of the five building structural upgrades described in this report. For the High School gym, two alternatives were examined (upgrade the complete building for PGA = 0.47g, or just decouple the non-structural masonry walls from the rest of the building). The results for each of the five analyses are provided in Table 6-1.

School Building	Seismic Upgrade Cost	Project Benefits	Benefit Cost Ratio
Middle School	$1,251,510[11]	$8,132,160	6.50
Ouzinkie (1969 portion)	$149,000	$975,410	7.55
Peterson (1946 portion)	$508,500	$1,862,173	3.66
High School Library Wing	$464,500	$4,452,695	9.59
High School Gym (Essential upgrade)	$410,300	$416,768	1.02
High School Gym (Decouple walls)	$40,000	$250,369	7.26
Non structural equipment and items	$348,480	-	-
Total (with HS essential upgrade)	$3,132,290	$15,839,206	5.06

Table 6-1. Results of Benefit Cost Analyses – Structural Upgrades

An upgrade with a BCR greater than 1 has more benefits than costs and should be pursued by KIB. With this in mind, all of the upgrade projects are cost effective, although some clearly more so than others.

With regards to the High School Gym upgrade, two options were considered. In the first option, the existing non-structural masonry walls are substantially upgraded into reinforced concrete shear walls, and the building's existing steel braced frame and roof are upgraded to make it stiffer and stronger to resist smaller earthquakes, and provide about 20% more capacity than the existing building to resist larger earthquakes. By ignoring the benefits that accrue that the Gym could be considered an emergency shelter post-earthquake for people displaced from other damaged structures, the BCR is 1.02. This shows that modest upgrades (about 20% more strength) provide only modest improvement, even given the very high seismicity in Kodiak. The alternative choice, which is to decouple the weak non-structural walls from the main lateral force resisting system, appears to offer a better BCR (7.26 versus 1.02), but would provide no improvement in using the Gym as an emergency shelter. We selected the more expensive

[11] Includes relocation costs during construction where occupancy will likely be impacted during construction.

"essential upgrade" for the recommended upgrade of the Gym, and this is listed in the Executive summary of this report.

A cost of $348,480 is listed for the non-structural upgrades at all the schools except the Middle School, and an additional $10,966 included in the Middle School cost estimate (covers 990 items). Table 6-2 lists the items needing anchorage / restraint at each school, including upgrade costs. The BCR in the Totals in Table 6-1 includes the costs for these non-structural upgrades but no benefits for schools without structural upgrades, so the Total BCR is actually somewhat higher than those listed in Table 6-1.

7.0 References

Goettel & Associates, Kodiak Island Borough, Alaska, Seismic Retrofit Project: Middle School, Benefit Cost Analysis Executive Summary, February 2, 2006.

WLA, 2006, Kodiak Island Borough School District, Geologic and Geotechnical Seismic Vulnerability Assessment, William Lettis and Associates, February 10, 2006.

Building	File Storage Cabinet	Drink / Water Dispenser	Windows	Communication Rack	Sprinkler Heads in Weak Ceilings	Desk Top Monitors, Countertop items	Kitchen Item (Fridge)	Small Bookcase	Medium Bookcase	Tall Bookcase	Furnace	Brace Expansion tanks or Rod Supported Items	Electrical Cabinet	Storage Tank	Generator / Vibration Mtd Item Restrain	Battery, cylinder Restrain	Item in Rack / Counter Slide and Fall	Total Number of Items	Total Costs
	Item	Item	Item	Item	Item	Item	Item	Item	Item	Item	Item	Item	Item	Item	Item	Item	Item	Total	Building
KBB Upper Level w/ south side					36													36	$ 3,292
KBB Lower Level					18													18	$ 1,650
Learning Center 1	7	2			-	16	1	2	1	2	1	2	1	1				36	$ 13,503
Vocational High Classrooms East+West					120	40					2	6	2	1	7	1	1	180	$ 40,975
Gym Basketball + wrestling gym					-													-	$ -
Library wing two floors, plus common area	1				55	4				14								74	$ 13,373
Pool					-													-	$ -
Kitchen Addition					3										2			5	$ 3,908
Mat Room					17													17	$ 1,531
Maintenance Shop					-													-	$ -
Auditorium					4													4	$ 363
Middle Corner 1952 Original					10						2	1		1		10		24	$ 10,422
Middle Addition 1954 Gym Area					8													8	$ 725
Middle 1959 North Classroom Addition					6													6	$ 544
Middle 1962 North Addition					4												4	8	$ 1,088
Miiddle 1962 East Addition					10													10	$ 906
Main Elemetary					26	20				8	1			2	1		3	61	$ 13,594
East Elementary Original			16		44	24	4			7	1	1	1	2			3	103	$ 75,718
East Elementary					14													14	$ 1,230
East Elementary					23													23	$ 2,048
Northstar Elementary					-	15	2				2		1	5	2		4	31	$ 14,319
Peterson Elementary	3				-	13	4		10						4		4	38	$ 14,138
Chiniak					15	9	1			8	1	2		3	8	6		53	$ 29,214
Old Harbor Old Gym					3													3	$ 272
Old Harbor New Classroom School	6	2		1	-	12			2	3	2	3		2	1		1	35	$ 17,763
Akhiok	2				7	15	1		3	3	1	2	3	2	2	4		45	$ 20,934
Karluk	2				7	15	2		3	3	1	3	3	4	2	4		49	$ 23,200
Larsen Bay Gym	4			1	8	10			1	19	2	3		2	4	4		58	$ 32,081
Larsen Bay classroom					-													-	$ -
Port Lions	2	1		1	-	18	3		1	3				3	1		6	39	$ 12,234
Ouzinkie 1969					-													-	$ -
Ouzinkie 1985-1993					-	13	3		1		1	1		3	3	2		27	$ 13,141
Total	27	5	16	3	437	224	21	2	22	70	17	24	11	31	37	31	26	1,004	$ 362,164
Installation cost per item	$ 250	$ 250	$ 2,000	$ 1,000	$ 50	$ 50	$ 250	$ 100	$ 100	$ 300	$ 1,000	$ 500	$ 1,000	$ 250	$ 1,000	$ 250	$ 100		
Contractor mobilization, profit (25%)	$ 75	$ 75	$ 600	$ 300	$ 15	$ 15	$ 75	$ 30	$ 30	$ 90	$ 300	$ 150	$ 300	$ 75	$ 300	$ 75	$ 30		
Total Construction	$ 325	$ 325	$ 2,600	$ 1,300	$ 65	$ 65	$ 325	$ 130	$ 130	$ 390	$ 1,300	$ 650	$ 1,300	$ 325	$ 1,300	$ 325	$ 130		
Soft Costs (eng, inspect, proj admin 45%)	$ 146	$ 146	$ 1,170	$ 585	$ 29	$ 29	$ 146	$ 59	$ 59	$ 176	$ 585	$ 293	$ 585	$ 146	$ 585	$ 146	$ 59		
Total Costs per Item	$ 471	$ 471	$ 3,770	$ 1,885	$ 94	$ 94	$ 471	$ 189	$ 189	$ 566	$ 1,885	$ 943	$ 1,885	$ 471	$ 1,885	$ 471	$ 189		
Total Costs	$ 12,724	$ 2,356	$ 60,320	$ 5,655	$ 41,215	$ 21,112	$ 9,896	$ 377	$ 4,147	$ 39,585	$ 32,045	$ 22,620	$ 20,735	$ 14,609	$ 69,745	$ 14,609	$ 4,901		